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D 3.2 Risk Assessment Review

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Risk Assessment Review

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C o n t e n t

Glossary

AIC	Akaike Information Criterion
AADT	Average Annual Daily Traffic
AAHSTO	American Association of State Highway and Transportation Officials
ARRB	Australian Road Research Board
BIC	Bayesian Information Criterion
CCR	Curvature Change Rate
CPM	Crash Prediction Model
DC	Degree of Curvature [deg/100ft]
EC	European Commission
ERF	European Union Road Federation
EuroRAP	European Road Assessment Programme
GLM	Generalized Linear Modelling
GLR	Generalised Linear Regression
GPS	Global Positioning System
IHSDM	Interactive Highway Safety Design Model
IHSDM-DCM	Interactive Highway Safety Design Model – Design Consistency Module
IASP	Identification of Hazard Location and Ranking of Measures to Improve Safety
iRAP	International Road Assessment Programme, active in more than 60 countries throughout Europe, Asia Pacific, North, Central and South America and Africa. iRAP is the umbrella organisation for EuroRAP
MSSC	Mean Summer SCRIM Coefficient
MMS	Mobile Mapping System
NCHRP	National Cooperative Highway Research Programme
NSM	Network Safety Management
RAPID	Road Assessment Programme Inspection Device
RDBMS	Relational Database Management System
RHI	Roadside Hazardousness Index
RIPCORD-ISERET	Road Infrastructure Safety Protection - Core Research and Development for Road Safety in Europe; Increasing Safety and Reliability of Secondary Roads for a Sustainable Surface Transport
RNSA	Road Network Safety Assessment
RSI	Road Safety Inspection
SFC	Sideways Friction Coefficient
SPI	Safety Performance Indicator
RSDI	The Road Safety Development Index

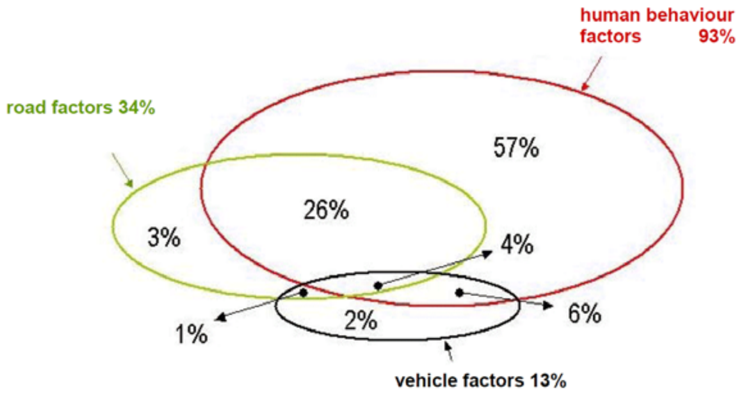
Nomenclature

DC	Degree of Curvature [deg/100ft]
ΔDC	Change in Degree of Curvature [deg/100ft]
V_D	Design Speed
V_{85}	85th percentile of the distribution of observed speeds under general free-flow conditions
V_{SP}	Safe profile velocity, V_{SP}, is recorded using onboard GPS under typical (daylight, fair weather, free-flow) conditions, ideally, at the same time as the mobile mapping system data-acquisition. The driver is instructed to drive so as to ensure a safe, comfortable driving profile over the entire survey section. V_{SP} can be used as a proxy for perceived risk of the static road factors, as measured by the mobile mapping system.
ΔV_{85}	Change in 85th percentile of the vehicle operating speed between adjacent road elements

1 Introduction

1.1 Background

Many factors influence road transportation safety standards across Europe. These factors include road safety policy, traffic flow, vehicle condition road network characteristics, human behaviour and attitudes, travel conditions, environment, etc. These issues have been studied for a number of decades and have improved our understanding of risk assessment in the context of safe movement and travel for all road users. Risk is a measure of the probability and severity of adverse effects (Haimes, 2009) where probability is a mathematical construct and severity is the potential damage or unfavourable adverse effects arising from a road accident. Accident risk has been applied extensively in transportation safety analysis. Risk is often used to describe the level of safety in transportation systems by incorporating a measure of exposure, such as traffic flow. The most commonly applied definition of accident risk states that risk is a linear function of accidents and traffic flow. This definition, however, creates problems for transportation systems that are characterized by a nonlinear relationship between these variables (Lord, 2007). There is general agreement that although the human element is the key causal factor of road accidents (PIARC, 2007), the influence of road factors in terms of infrastructural and environmental components plays a significant role in accidents occurring on route networks, especially along rural roads where the majority of fatalities and injuries occur (ERF, 2008).



Contributing factors to road accidents (PAIRC, 2007)

Average fatal accident rates per vehicle km can be up to six times higher on 2 lane rural roads than on motorways, and decrease as traffic flows increase, Lynam et al. (2004). The density of severe (fatal and serious injury) accidents per km is typically greatest for divided carriageways below motorway standard, but less than twice that on motorways or 2 lane roads. Eighty per cent of all fatal accidents on major interurban roads occur due to single vehicles leaving the road, impacts at junctions, head-on impacts with opposing vehicles or impacts involving vulnerable road users, Lynam et al. (2003); OECD (1999). The proportion within each of the four groups varies between countries depending on the characteristics of their road network and the traffic flow levels, Lynam et al. (2005). The proportion also varies between road types, and at different flow levels. In Europe, approximately 60% of road accident fatalities occur on two-lane rural roads, Cafiso et al. (2010). In order to reduce casualties on European roads the European Union has highlighted the necessity to develop suitable instruments to improve traffic safety on roads. These tools are listed within the European Directive of Road Infrastructure Safety Management (Eu Directive 2008).

Typical rural road network environments across Europe

This EU-directive defines four types of instruments which should help to improve road safety:

- Road Safety Impact Assessment
- Road Safety Audit
- Safety Ranking and Management of the Road Network in Operation and
- Safety Inspections

Within the Article “Safety Inspections” it is stated in the directive that the member states shall carry out safety inspections on existing roads in order to identify the road safety related features and to prevent collisions. These inspections should be performed periodically and by a competent entity. In the EU directive “safety inspection” is defined as an “ordinary periodical verification of the characteristics and defects that require maintenance work for reasons of safety.”

This report focuses on risk assessment along rural road networks following a Road Safety Inspection (RSI). Risk assessment should include some of the intrinsic factors gleaned from a RSI such as road geometry, road side hazards in addition to additional inputs such as pavement condition, traffic flow and accidents. A review of various RSI methodologies has already been carried out in a preceding work-package WP3.1 within this EuRSI research project. A number of relevant conclusions and recommendations were listed including, a general definition of RSI and use of accident statistics;

An RSI is comprehensive, with extensive preliminary work, on site appraisal including detailed checklists, analysis of the problems and suggested countermeasures. However, RSI can be prompted by spots where collisions often occur, EuRSI Report 3.1 (2011a).

Safety risk assessment is not really associated with RSI but Recommendation 4 of the aforementioned report points to the usefulness of accident data for carrying out dedicated road survey inspection;

Recommendation 4

It is recommended that collision data be analysed in advance of 'Dedicated road-safety inspections', but for 'Periodic road-safety inspections' the focus should not be on past collisions, but rather anticipating what can happen in the future, EuRSI Report 3.1 (2011a).

There are also a number of issues that need to be considered in devising a common approach to safety risk assessment, some of which fall outside the remit of this report;

- *What exactly do we mean by safety risk assessment in the context of Road Safety Inspection along rural road networks?*
- *Should road safety risk assessment be a subset of the Road Safety Inspection process or vice-versa, should outputs of Road Safety Inspection feed into a road safety risk assessment?*
- *What is the role of historic accident databases and exposure models in determining safety risk? How should these data inputs be utilised?*
- *What is the end-use business case for carrying out this road safety risk assessment in the context of RSI?*
- *Should the wider benefits of crash reduction measures (AustRoads, 2010) and new safety interventions following a RSI and associated risk assessment be considered in the context of an overall road network management tool?*

- *What type of risk assessment information do we require in terms of content, quality, usefulness, availability etc?*
- *What factors, features, inputs should be included e.g. Geometry, Surface Condition, Hazards, Existing Safety Interventions?*
- *What is the best approach to modelling these inputs for example, should a qualitative or more rigorous quantitative approach be adopted?*
- *How can this methodology be applied within a wider European context?*

The initial starting point for this report is the overall objective ***"to formulate a road safety risk assessment methodology to highlight locations and sections along rural road network that require safety interventions based on information acquired during RSI and any other relevant information"***. This report, therefore, describes best practice and a contemporary review of published research, methodologies, projects and initiatives that can help formulate a risk assessment framework within the context of RSI along rural road networks.

1.2 Structure of this Report

This report attempts to address the current shortcoming here in Europe in adopting a common approach to risk assessment along rural roads against the backdrop of RSIs. The remainder of the report comprises the following four chapters;

- Chapter 2: Review of road safety factors and risk assessment methodologies
  This chapter reports on contemporary research & projects relating to crash prediction models, risk assessment with particular emphasis on rural roads.

- Chapter 3: Understanding the factors and data sources that are relevant to assessing risk within the context of Road Safety Inspection
  This chapter details the various static road factors relevant to risk assessment following an RSI as well as investigation the role of accident databases and vehicular speed in detecting and explaining risk

- Chapter 4: A proposed framework for assessing risk within the context of road safety inspection along rural roads

This chapter describes a framework which could help formulate a more concise methodology and provide a common European approach to risk assessment along rural road networks, linked to the overall objectives for carrying out RSIs.

- Chapter 5: Conclusions & Recommendations

  This final chapter presents the conclusions and recommendation for detecting and explaining risk along rural road networks following an RSI.

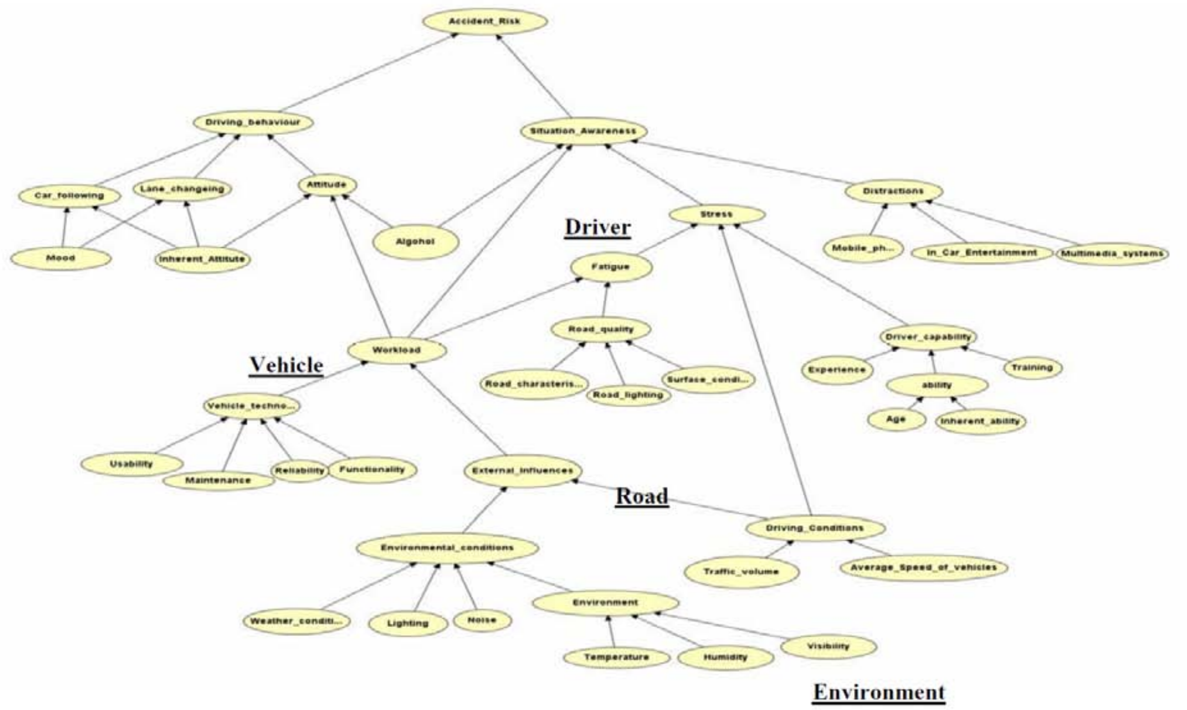
2 Review of road safety factors and risk assessment methodologies

2.1 Introduction

In this section various approaches to understanding road safety factors and modeling risk along road networks, as reported in literature and larger research initiatives are described. Factors include road geometry, surface condition, traffic flow and hazards whilst modeling approaches tend to focus around constructing performance indices or generalized linear regression models. However, identifying and measuring these various factors and building models to help us understand and predict problems is non-trivial. The larger research initiatives are usually managed as part of a national or international research initiative that is structured around a comprehensive work-plan with emphasis on developing more applied methodologies and conducted with wider engagement of stakeholders either during testing and or implementation

Gregoriades (2007) catgorises reports that contemporary research into road safety performance can be divided into macro and micro approaches. Macro approaches takes a holistic view of the road traffic system where accidents are caused by coordinated events of the system's components which give rise to accident patterns whereas the micro approach considers accidents on an individual component basis and investigates the dynamics of each component's supporting sub-elements. He described how macro level analyses used statistical techniques to give an aggregated view of historical data and with the use of regression analyses to make projections on future system states. These were categorized into four groups: averages from historical accident data, predictions from statistical models based on regression analysis, results of before-after studies, and expert judgments by experienced engineers. However he states that all these have inherent weaknesses. Estimates from historical accident data suffers from high variability. Estimates from statistical models use data of accidents with roadway characteristics (traffic volumes, geometric designs features) in a regression analysis to predict the expected total accidents in particular locations.

Regression models on the other hand can lead to unreasonable interpretations of the outcomes. Before-and-after studies have been used for many years to evaluate the effectiveness of highway improvements in reducing accidents. However, most before-and-after studies have design flaws which lead to ambiguous results. Finally, estimate from expert judgment is a feasible method only if the experts have a point of reference due to their inability in making quantitative estimates. Gregoriades (2007) found that at the micro level, research ranges from driving behaviour, human performance, man-machine system reliability, vehicle kinematics and vehicle ergonomics. He stated that multi-agent systems were promising for modeling micro level analyses due to their inherent capabilities of dealing with complex interaction among system elements. The complexity of modeling the three main sources of risk is evidenced in Gregoriadess combined Bayesian Belief Network (BBN), road network simulation and agent based approach



BBN Model (after Gregoriades, 2007)

Cafiso et al. (2010) reported that a reasonable amount of research effort had been carried out in building accident models for two lane rural road sections. This paper included Garber and Ehrhart (2000) who considered road sections between two major junctions and, using a multivariate ratio of polynomials, and found the variables “standard deviation of the speed profile” and “flow per lane” to be strongly correlated to crash rate. Zhang and Ivan (2005) calibrated negative binomial regression models for a sample of segments of constant 1 km length and found a significant relationship between accidents and speed limit, “the sum of the change rate of the horizontal curvature”, “the sum of the change rate of the vertical curvature” and “the maximum horizontal curvature rate”.

Cafiso et al. (2010) also reported on work by Pardillo and Llamas (2003) who proposed negative binomial regression models for two definitions of segments: (1) 1km fixed length segments, and (2) network links joining two consecutive nodes with variable lengths ranging from 3 to 25 km. They found significant correlations between accidents and access density, average sight distance, average speed limit and proportion of no passing zones, revealing a need to use these variables in defining homogeneous sections with suitable lengths not less than 400m. Abdel-Aty and Radwan (2000) divided a 227km long road into 566 segments with homogeneous characteristics in terms of traffic flow and geometry (degree of horizontal curvature, shoulder and median widths, rural/urban classification, lane width and number of lanes), all variables found to be strongly related to the accident occurrence. The research concluded that to obtain a reliable accident prediction model, sections should be 0.8km or longer.

Cafiso et al. (2010) found that perhaps the most significant US research of late has been the calibration of models that formed the basis for those applied in the Interactive Highway Safety Design Model (IHSDM), Paniati (1996) and, lately, the Highway Safety Manual due for release in 2010. That research (Bared and Vogt, 1998) related accidents per unit of exposure (defined as the product of traffic volume and segment length) to lane width, shoulder width, roadside hazard rating, horizontal curvature, vertical grade and curvature, and driveway density. Cafiso et al. (2010) reported on another IHSDM related effort by Fitzpatrick et al. (2000) who found that the average radius of horizontal curves for a roadway section showed promise as design consistency measure, but did not appear to be as appropriate a measure of design consistency as the speed reduction for individual horizontal curves.

Turner et al. (2011) reported on, largely, New Zealand based research centered on crash prediction models, typically for one-off evaluations of specific features or policies. These included McLarin et al. (1993), who investigated the impact of terrain characteristics (e.g. flat, rolling and mountainous) on crash rates, Chadfield (1993), who looked at the impacts of lane and shoulder width and shoulder slope on crash rates, Jackett (1992), who looked at crash rates and curve radii, Koorey and Tate (1997), who looked at how alignment consistency and speed limit impacted on crash rate and severity, Turner (2000), who investigated the relationship between traffic volume and crash rates, Cenek et al. (2004), who looked at the impact of road surface friction on crash rates, Turner et al. (2004), who looked at the crash rate implications of roadside hazards and research by Cenek and Davies (2008), which looked at the safety benefits of engineering measures such as high-friction surfacing and realignment.

2.2 Risk Evaluation by Modelling Passing Behaviour

One approach to risk assessment from Farah et al., (2009) focuses on the passing manoeuvre on two-lane rural roads, but includes other factors as well. The risk of the passing manoeuvre is defined as “the remaining gap between the passing vehicle and the oncoming vehicle at the end of the passing process". This approach includes also a model which uses variables that capture both the impact of the attributes of the specific passing gap that the driver evaluates (e.g. speed of the subject vehicle, speed of the lead vehicle and the following distance it keeps from the vehicle in the front), the road geometry and the driver characteristics (gender and age). It can be assumed that all these variables significantly influence the passing behaviour. This model makes it possible to predict the risk level on existing two-lane roads or new design roads as a function of its geometry, traffic and drivers' characteristics.

2.3 Assessing Crash Risks on Curves

Chen et al., (2007) developed a risk assessment model, which concentrates on accident risk on road curves. The approach uses records from insurance companies to determine significant contributory factors for accidents. This type of risk is relevant since the accident rates in road curves are about 1.5 to 4 times higher than in straight roads. In addition to that, the accident severity for curve related accidents is higher than those occurring on straight roads. The aim is to define potential accident risks. In general there are two different methods to assess risk on curves. While the first method focuses on the number of fatalities or accident severity on curved roads, the other method looks at the contributing factors of an accident and determines the effect of each factor on risk. These factors are related to vehicle, driver and environment. In this model five risk levels are defined and contributing factors to accidents are determined from accident records from an insurance company. Afterwards a statistical analysis is carried out to determine the significant contributing factors. This study is representing the type of models that focus on specific risk areas (curves) only.

2.4 Effects of Geometric Design Consistency on Road Safety

Geometric design consistency was highlighted during the project Effects of Geometric Design Consistency on Road Safety (CJOCE, 2011). The identification and the treatment of inconsistency on a highway can significantly improve its safety performance and has been explored during multiple research projects including the development of models to estimate them. However, little work has been carried out to quantify the safety benefits of geometric design consistency.

The objectives of this study were investigation and quantification of the relationship between design consistency and road safety. A comprehensive accident and geometric design database of two-lane rural highways was used to investigate the effect of several design consistency measures on road safety. Several accident prediction models that incorporate design consistency measures were developed. The generalized linear regression approach is used for model development. The models can be used as a quantitative tool for the evaluation of the impact of design consistency on road safety. An application is presented where the ability of accident prediction models that incorporate design consistency measures is compared with those that rely on geometric design characteristics. The paper concludes that models that explicitly consider design consistency may identify the inconsistencies more effectively and reflect the resulting impacts on safety more accurately than those that do not.

2.5 Road side point hazards

An Austrian diploma thesis reported on research based on traffic accidents with roadside trees in Styria Wrusz (2007). This accident type was found to have special characteristics centred around vehicle accidents with trees along sections of Austrian roads from 2001 to 2004. The accidents were analyzed and compared using several parameters which affect the geometric parameter of the street.

These parameters were:

- vertical alignment, grade and width
- surface quality and road condition
- street furniture
- distance between trees and the road as well as distance between single trees,
- diameter of the tree,
- environmental factors such as weather, and visual conditions.

The diploma thesis proposed a catalogue of measures to assist during safety investigations but did not include a risk analysis.

2.6 Bayesian hierarchical approach for developing safety performance functions

Ahmed et al., 2011 presented an exploratory investigation of the safety problems of a mountainous freeway section of unique weather condition. They reported that factors affecting the occurrence of crashes could be conceptually categorized into two groups, associated with crash exposure and crash risk, respectively.

Crash occurrence ~ Crash exposure X Crash risk

While exposure factors account for the amount of opportunities for crashes which traffic systems or drivers experience, the risk factors reflect the conditional probability that a crash occurs given unit crash exposure. Hierarchical Full Bayesian models were developed to relate crash frequencies with various risk factors associated with adverse weather, road alignments and traffic characteristics. Using the calibrated model, the sites were ranked in term of crash risk for further safety diagnostics and mitigation. Season was found to significantly affect crash occurrence, the risk of crashes during snow season was approximately 82% higher than the crash risk in dry season, given all other variables constant. The increased crash risk within the snow season may be explained by the confounding effect of the snowy, icy, or slushy pavement conditions during the snow season, and exacerbated by the steep slopes. The effects of various slopes are compared to Grade-8 (reference condition, steep slope ranges from −6% to −8%). Grade-8 is the most hazardous slope followed by Grade-4, Grade-7, Grade-2, Grade-6, Grade-3, Grade-5 then Grade-1.

In regard to the curve effect, although not statistically significant, the result implies that a unit increase in Degree of curvature is associated with a 5% decrease in the crash risk, with all other factors equal. It is not uncommon that high degree of curvature was found to be associated with decrease in crash likelihood. Other variables included in the models are Number of Lanes and Median Width. Results revealed that segments with three lanes are 40% less in crash risk than two-lane segments, with all other factor being equal. Median width is associated with a tiny positive effect, which is only significant in the Poisson model. The increasing safety associated with wide median is well known as median works as division for traffic in opposite directions and a recovery area for out-of-control vehicles.

2.7 Safety Assessment on Accidents, Traffic Flow and Facilities

Wang et al. (2008) suggest a systematic assessment index for evaluating safety performance on rural freeways. The index consists of three separate indices that are as follows: index related to historical accident data, index relating to traffic flow characteristics and index relating to feature of road and traffic facilities. The last index, defined as Facility Safety (FS), can be seen as an accident-prevention assessment index because it focuses on road and traffic facilities and can therefore be determined before accidents happen. Ensuing treatments contribute to the reduction of the number of accidents.

2.8 5-level Roadside Hazardousness Index

Another project that dealt with the creation of an index is the 5-level Roadside Hazardousness Index (RHI) from Pardillo-Mayora et al. *(2010).* This index concentrates on run-off-road accidents. Four indicators that characterize the main roadside features that affect the consequences of roadway departures were defined:

- roadside slope degrees,
- non-traversable obstacles offset from the roadway edge,
- safety barrier installation,
- and highway alignment.

As part of the project a cluster analysis has been carried out to group the combinations of the four indicators into categories with homogeneous effects on injury accidents frequency and severity. The analysis of the research project has shown significant differences in injury accident frequency and severity rates between the five roadside condition clusters. Based on these results, a 5-level Roadside Hazardousness Index (RHI) was defined. This index can be used for instance when deciding about installation of safety barriers. The installation should be considered on those sections, which have RHI values (levels) higher than two (from five levels).

2.9 Road Safety Framework

The approach of A. Yildiz (2009) is based on data that is collected through Road Safety Inspections in Austria. The main innovation is that instead of dividing roads into sections and assigning the hazards to sections the system assigns every safety hazard to its very spot. Furthermore this approach distinguishes between active and passive safety hazards: the active hazard affects the accident risk, the passive hazard has an influence on accident severity. For instance active hazards like water grooves (as a result of heavy rain) raise the risk of an accident whereas passive hazards like uncovered bridge piers have no influence on accident risk, but can worsen the outcome of an accident. The results are two separate road scores: one for active safety and one for passive safety. In addition to the influence on the very spot, each hazard can also affect a certain length of the road before and after its position. Further, a risk value has to be assigned to each hazard. This value can be between 0 and 100, where 0 stands for safe and 100 for unsafe. At the end, the road including the scoring is displayed on a map. As part of the innovative calculations the risk of a roadside hazard is not only calculated at its prime location, furthermore the distance between the vehicle and the hazard is also considered and therefore the hazard has an effect on the adjacent road section.

2.10 Comprehensive accident models for two-lane rural highways

Cafisco et al. (2010) described a novel and extensive data collection and modelling project 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. The first part of the paper described how these were identified for the segmentation of highways into homogeneous sections. A description of the extensive data collection based on DGPS video 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 focused on the calibration of models for estimating accidents on homogeneous sections that could be characterized by constant values of the explanatory variables. Several candidate models were considered for calibration using the Generalized Linear Modelling (GLM) approach. Nineteen models were ranked and three were selected, the first of the three was a base model, with length and traffic as the only predictor variables; since these variables were the only ones likely to be available network-wide, this base model could be used in an empirical Bayesian calculation to conduct network screening for ranking “sites with promise” of safety improvement. The other two models represented the best statistical fits with different combinations of significant variables related to exposure, geometry, consistency and context factors. These multiple variable models could be used, with caution, and in conjunction with results from other studies, to derive accident modification factors for these variables for design applications, and in safety assessment for smaller samples of sites for which these variables could be assembled with relative ease.

2.11 Web GIS for Road Risk Anaysis

Pirotti at al. (2011) described a Web GIS based on PostgreSQL RDBMS and Mapserver components that enabled multi-user access to an online portal for road risk analysis. Simplified risk models based around hazard and risk were constructed from historic accident data and road length information. Road networks were divided up into 50m segments.

Indicator	Formula	Parameters
Fatality Rate (FR)	$FR = \left(\frac{D}{A}\right) * 100$	D = Deaths, A = Accidents

Injury Rate (IR)	$IR = \left(\frac{I}{A}\right) * 100$	I = Number of injured persons
Hazard (H)	$H = \left(\frac{D}{D+I}\right) * 100$	
Risk (R)	$R = \left(\frac{A}{L}\right)$	L = segment length

Although the modelling approach is quite simplified, this project demonstrated the advantage of a central, online collaborative portal for collating, analysing and visualising road risk factors.

2.12 European Road Assessment Programme EuroRAP

The European Road Assessment Programme (EuroRAP) is an international non-profit organisation registered in Brussels which has been created by motoring organisations and road authorities throughout Europe to improve safety on European roads. EuroRAP provides a safety rating for roads and highlights those sections with the highest risk of death and serious injuries EuroRAP (2008). EuroRAP is part of the International Road Assessment Programme (iRAP), which is the umbrella organisation for a series of programs adjacent to EuroRAP: AusRAP (Australian Programme), KiwiRAP (New Zealand's programme) and usRAP (United States Road Assessment Program), IRAP (2011).

EuroRAP consists of four protocols for assessing and improving the safety of roads EuroRAP (2009) but only two protocols Risk Maps and Star Ratings are really relevant to EuRSI:

<u>EuroRAP Risk Maps</u>
This protocol (EuroRAP, 2010a), provides risk ratings on maps that show the density of traffic collisions which caused death and life threatening injuries, Yildiz (2009). Thus the categorisation of road sections is based on accident data.

The visualisation on maps allows a simple identification of safe and unsafe road sections. They also allow a comparison of safety performance. The indicators are based either on the road network, accident numbers or traffic flow. Currently there are four types of maps which are produced:

- Risk per kilometre
- Risk per vehicle kilometre travelled
- Risk in relation to roads with similar flow levels
- Economical potential for accident reduction

The risk mapping protocol distinguishes between the following two types of risks:

- Individual risk of road users and
- Collective risk of a community.

Star Ratings

The second protocol Star Ratings (EuroRAP 2009) encompasses also the road infrastructure. This protocol evaluates the safety of the road section through its design in combination with the way traffic is managed on it. A scale for Star Rating is the *Road Protection Score (RPS),* which informs the vehicle drivers how well they are protected by the infrastructure from death or serious injuries in case an accident occurs, EuroRAP (2010c).

Star Rating consists of the following components:

- Road Rating,
- Road Inspection,
- Road Protection Scores (RPS) and
- Star Ratings.

These components also constitute the steps by performing Star Rating. The next step is the Road Inspection. It is a detailed visual inspection of the road infrastructure elements that are known to have an impact on the probability of an accident and its severity. There are two types of inspections: drive-through inspections and video-based inspections. Drive-through inspections are conducted by at least two investigators who record the road infrastructure elements with the *RAP inspection device* (RAPID). This system includes a video-camera, touch-sensitive laptop and Global Positioning System (GPS). Generally only the high-level road infrastructure elements are recorded during the inspection itself. Additional data is imported later on. Video-based inspections are different from drive-through inspections. The data is collected by video and the analysis of road infrastructure elements is carried out afterwards.

The video recording is carried out with a specially equipped survey vehicle which records images of a road at intervals of 5-10 meters using an array of cameras which are able to pick up panoramic views and measure key road infrastructure elements. The GPS system is used to allocate a precise location to each individual video image. The analysis is carried out with specialised software to measure infrastructure elements such as lane widths, shoulder widths and distance between the road edge and hazards such as trees and additional roadside objects within distance bands (3m, 5m, 7m) from the road edge. The outcome of both inspection types is a detailed road condition report which summarizes many roadway characteristics for the EuroRAP network. The inspected road is divided into 100 metre road sections and the results are produced for every 100 metre section separately.

Inspectors have to categorize road infrastructure elements based on their condition. For example the element delineation can be assigned to one of two categories: adequate or poor. Each of these two categories is assigned to a risk factor (this is the *accident likelihood factor*). As an example: the risk factor of an adequate delineation is 1.00, the risk factor of a poor delineation is 1.20. Therefore the risk of death or serious injury is 20% higher when the delineation is poor. This procedure already belongs to the next step of Star Rating, the Road Protection Score (RPS). Other infrastructure elements such as road signs, trees, poles and ditches can also influence the *severity* of an accident. Therefore *accident severity factors* are assigned to these elements. For example, the relative risk for safety barriers is 1.75, whereas the relative risk for deep drainage ditches is 5.00 which is almost three times higher.

The output is a risk matrix, where the two factors mentioned above, accident severity factors and accident likelihood factors are combined. This allows an overall assessment of risk, Lynam, et al. (2007). The total risk is the combination of the *likelihood* of an accident occurring and the resulting potential consequence (injury *severity*). An important aspect of this approach is that only road infrastructure elements are taken into consideration that influence on the following three main types of accidents:

- Run-off road
- Head-on
- Intersection based

Finally, on the basis of the Road Protection Score (RPS) the Star Rating itself can be performed. Each RPS is allocated to one of five Star Rating bands. The best performing category is the 5-star (green) category; the worst category is the 1-star (black).

The calculation of risk factors for individual parameters is a vital part of the EuRSI project. Therefore the protocol Star Ratings is of great benefit for the project. Nevertheless when it comes to the evaluation of single parameters there are some limitations within the protocol. During the review of Star Ratings no information could be found in relation to the horizontal and vertical curvature. These parameters also have a high impact on road safety. Furthermore locations of hazards throughout the network are not evaluated separately (the risk of a tree adjacent to a straight section in comparison the tree on an isolated bend. Furthermore the protocol does not take into consideration roadside development such as number of accesses.

The analysis of the EuroRAP approach highlights some shortcomings. One issue is the focus on only three main accident types (Run-off road, Head on and Intersections). Consequently only safety issues/problems are recorded, which have an impact on one of these three accident types. Although these three accident types account for approximately 80% of vehicle occupant deaths on major rural roads EuroRAP (2009), the remaining safety issues cannot be determined. The second area is the assignment of the safety issues into a brief number of categories only. Additional categories should be included. Furthermore the connection between the protocols *Risk Maps* and *Star Ratings* is missing. The first protocol mentioned above concentrates on accidents, the second protocol on road infrastructure elements. A combined approach could be very useful. The results could be presented in a single map instead of two separate maps showing either the level of risk or the star rating.

2.13 Road Network Safety Assessment (AARB, Australia)

The Road Safety Audit process in Australia includes a comprehensive analysis of multiple indicators that affect road safety. For existing roads, the Department of Transport and Main Roads conducts road safety audits on sections of roads and intersections which are identified as potentially the most hazardous using the Road Network Safety Assessment (RNSA), incorporating the Road Safety Risk Manager (RSRM) tool, AustRoads (2010). The assessment which has been developed by the ARRB Group is carried out within a period of two years, starting with the higher risk roads.

The risk based tool was designed to identify the safety performance of a length of road by measuring the inherent safety built into the road and the roadside environment. The process involves the review of road video surveys, physically driving along the road and the rating of homogeneous sections recording risk scores for key engineering features and roadside conditions.

Those features are:

- For sealed rural mid-block sections: road type, roadside condition, horizontal alignment, lane width, shoulder width, delineation, overtaking opportunities, skid resistance and weather.
- For sealed urban mid-block sections: road type, roadside condition, horizontal alignment, lane width, shoulder width, delineation, parking, skid resistance, mid-block turning provision, pedestrian provision and weather.

- For rural intersections: intersection type, roadside condition, right turn provision, left turn provision, sight distance, alignment of legs, skid resistance, line marking, lighting and weather.
- For urban intersections: intersection type, roadside condition, right turn provision, left turn provision, sight distance, pedestrian provision, skid resistance, line marking, lighting and weather.

The methodology allows the assessment of urban and rural road segments and intersections. It has separate models for dealing with urban intersections, urban mid-block segments, rural intersections, sealed rural mid-blocks and unsealed rural mid-blocks. Each individual model considers the relevant attributes that influence road safety outcomes in that environment and considers both the likelihood and severity of accidents.

During the investigation for each defined homogeneous section risk scores for elements of the road (e.g. lane width, right turn provision, overtaking opportunities, and roadside condition) are recorded. The recorded risk scores are then entered into the safety assessment software. A network risk score that measures the overall safety performance of the section is then computed and issues exceeding the safety triggers and therefore requiring treatment are highlighted. The final output is a detailed prioritisation of sections and intersections that warrant further investigation and treatment.

The outputs from the assessment include the following:

- A summary of the network risk scores and safety issues presented in tabular form ranked from the highest risk to the lowest risk sites.
- Risk maps – GIS-based maps of the network colour-coded (based on network risk score) to depict high risk road sections and intersections.
- Network risk scores distribution and safety issues by road.
- Snapshots of key safety elements that have effect on road safety.

Great benefit of the RNSA tool is the ability to be used for road sections as well as intersections.

2.14 Ranking for European Road Safety (RANKERS)

The project Ranking for European Road Safety (RANKERS), is a European research initiative in the area of road safety engineering RANKERS (2011). The overall objective is to develop scientifically researched guidelines on road infrastructure safety enabling optimal decision-making by road authorities in their efforts to promote safer roads and eradicate dangerous road sections.

The proposed safety analysis tries to address all types of existing roads (dual-carriageways, motorways, rural and urban roads), integrate human behaviour and vehicle technology considerations and consider accident prevention and as well as mitigation. Road sections with road infrastructure deficiencies are identified through road inspections, video recording, road inventory analysis and the analysis of other complementary data.

Road infrastructure is analysed according to six different topics:

- Road alignment: lanes & shoulder width, curvature radius, visibility and longitudinal slopes coordination
- Road accesses: number of junctions and accesses present in the section and infrastructure status related to both of them.
- Overtaking: coherence between road marking and vertical signals overtaking and available visibility
- Roadside: geometry of the roadside, presence of obstacles and distance to the carriageway and safety equipment to their protection
- Pavement condition: assessment of the pavement status and super elevation coordination and transition in curves
- Road layout consistency: relationship between curvature of consecutive sections and the perception transmitted to drivers, including road markings and signals messages and visibility.

Major output of RANKERS is a road safety index that can be used for assessing and monitoring road safety. The index is based on objective, measurable parameters that assist during evaluation of the safety performance of a road or road segment. Furthermore a ranking of measures is being developed based on their benefit-cost efficiency allowing the end-user to choose the most appropriate solutions for implementation. The project innovation lies within the combined analysis of human and vehicle behaviour. The analysis is not limited to the event of the accident and the mitigation of its outcome. It also includes previous events leading to an accident.

2.15 SUNflowerNext

Within the SUNflowerNext, project a composite road safety performance index was developed, which consists of three types of indicators: road safety performance indicator, policy performance indicator and implementation performance indicator, Wegman et al. (2008).

While the first type of indicator describes the road safety quality which is most relevant for the EuRSI project, the second type expresses the quality of policies to improve road safety, and the third indicator represents the quality of the implementation of road safety policies which are not primarily relevant for EuRSI.

2.16 Identification of Hazard Location and Ranking to Improve Safety (IASP)

The project Identification of Hazard Location and Ranking of Measures to Improve Safety (IASP) has been developed by the University of Catania and has been approved and co-financed by the European Commission (DG TREN). Within the framework of the IASP project a methodological approach is developed for the safety evaluation of two-lane rural roads with low-medium traffic volume. This approach uses both analytical procedures (relating to alignment design consistency models) and the “safety review” process.

Within the framework of this project a Safety Index (SI) is calculated. It measures the relative safety performance of a road section IASP (2003). The index contains three components of risk: “the exposure of road users to road hazards, the probability of a vehicle being involved in an accident and the resulting consequences should an accident occur”. The mathematical formula is as following:

SI = Exposure Factor x Accident Frequency factor x Accident Severity factor.

The accident severity factor consists of two elements: speed and roadside hazards. These are for example trees, utilities, embankments etc. They include measured data of roadside safety items which are weighted (embankments have a relative weight of 3, bridges 5, ditches 1, etc.). Road safety inspection and design consistency evaluations are included in the accident frequency factor.

2.17 SafeSpot applications for infrastructure based road-safety

SAFESPOT was an Integrated Project co-funded by the European Commission, under the strategic objective *eSafety* Cooperative Systems for Road Transport. The Goal of SAFESPOT is to understand how intelligent vehicles and intelligent roads can cooperate to produce a novel road safety solution. Within the framework of this approach an application has been developed which warns drivers in case of dangerous events on the road. The most relevant safety events are accidents, the presence of unexpected obstacles on the road, traffic congestions, presence of pedestrians, presence of animals and presence of a vehicle driving in the wrong direction or making a dangerous overtaking. The cooperation of vehicles and roadside sensors enables the provision of warnings to the drivers. So the driver is informed about risks and can react on time.

2.18 Road Infrastructure Safety Protection – Core R&D for Road Safety in Europe (RIPCORD)

Road infrastructure related safety measures offer a large potential that could be exploited for a significant reduction of road accidents and their consequences. Considering that most casualties occur on single carriageway rural roads, RIPCORD-ISEREST, an European sponsored project (2005 – 2008) comprising a team of 17 partners, focused on road infrastructure measures for this type of roads. The objective of RIPCORD-ISEREST was to develop best practice guidelines based upon the current research results for:

- Road Safety Impact Assessment tools and Accident Prediction Models
- Road Design and Road Environment
- Road Safety Audit
- Road Safety Inspection
- Black Spot Management and Safety Analysis of Road Network

The project produced a number of reports including;

Road Safety Impact Assessment and Accident Prediction Model - Tools, Recommendation and Implementation Aspects

Road Design and Road Environment - Best Practice

Road Safety Audit - Best Practice Guidelines, Qualification of Auditors and "Programming"

Road Safety Inspection - Best Practice Guidelines and Implementation Steps

Black Spot Management and Safety Analysis of Road Network - Best Practice Guidelines and Implementation Steps

Recommendation for further research and standardisation activities

[Road User Behaviour Model]

[Best Practice Safety Information Expert System]

[Road Safety Performance Functions]

[GIS-based Decision Support Safety Tool]

[Demonstration of Tools and Measures for Safety Improvements on Secondary Roads]

[Safety Handbook for Secondary Roads]

[Road Infrastructure Safety Protection - Core Research and Development for Road Safety in Europe - Final Report]

The RIPCORD Safety Handbook for Secondary Roads (RIPCORD, 2005) gives an overview of parameters and correlations that have already been used for evaluation purposes:

- horizontal plan (radius, degree, curvature change rate, balanced elements, radii ration),
- vertical plan (grade, radius),
- cross section (lane width, shoulder width) and
- sight distance,
- ratio of consecutive curves,
- dimension of vertical curves and
- sight distance conditions

The handbook provides detailed information for every parameter, for example:

- As part of these investigations the correlation between the curvature change rate (CCR) and accident indicators has already been identified. The CCR is an appropriate value to characterise a road section with various curves. On such road sections the driving behaviour is not influenced by single elements but by the combination of consecutive elements. In sections with similar geometry the driven speed is constant. In general it is proved the higher the CCR the higher the risk of an accident. Especially CCR about 150 gon/km – 250 gon/km have shown high accident rates.
- A discontinuous alignment (for example: isolated curve between straight road sections) causes a higher accident risk than a continuous alignment. Because of these facts modern road design guidelines require a so called balanced alignment where the ration of radii of consecutive elements is within a defined range. The driven speed has not to be changed abruptly and therefore the risk of an accident decreases. Consecutive curves with a ratio smaller than 0.8 cause a significant higher accident risk.
- The vertical alignment has a smaller impact on road safety. Over the last decades numerous research works have shown a different influence of the vertical alignment on

road safety. Today an increasing accident risk in steep downgrades is proved. Vertical curves are distinguished in crests and sags. Both elements deal with different safety problems: for example crests typically imply problems with the sight distance.

- Regarding the lane width, the handbook includes results from multiple studies that have shown that lane widths of 3.4 – 3.7 m show the lowest accident rates.
- The impact of shoulder width or a shoulder in general shares various opinions. In general the design of shoulders regarding the pavement and width has positive influence on road safety. However wider shoulders have no positive safety impact.
- Sight distance affects road safety since it is the result of the geometry overlapped with the existing terrain and the influence of geometric parameters is proved. Several research works that are included in the handbook have shown the influence of sight distances on road safety. Short sight distances correspond with high accident frequency but also large sight distances might cause accidents.

Many of the reports produced within the RIPCORD are relevant to EuRSI is attempting to understand the factors, risk modelling approaches, role of GIS as well as the expert system SEROES (Secondary ROaDS Expert System). In terms of Accident Prediction Models (APM), RIPCORD's summary report concludes:

- Developing an APM is not an easy task, probably not suited for road authorities with the possible exception of national road authorities
- A good and detailed APM requires much data of good quality and detail that is not usually available
- As a result only a few explanatory variables (risk factors) are included
- APM can be quite different for the same road type in different countries
- Basic APM should be developed for several road types at a national level
- The term Basic means that no risk factors are included only traffic volume

2.19 European Road Safety Observatory

SafetyNet is an Integrated Project funded by DG-TREN of the European Commission. The central objective of the project is to build the framework of a European Road Safety Observatory, which will be the primary focus for road safety data and knowledge and support all aspects of road and vehicle safety policy development at European and national levels. This work includes developing common approaches across Europe in defining and collating exposure data, safety performance indicators (SPI), fatal causation databases as well as developing new statistical methods, SafetyNet (2007a).

Seven problem areas in road safety were selected for the development of SPIs in Europe, they are: alcohol and drug-use; speeds; protective systems; daytime running lights; vehicles (passive safety); roads (infrastructure) and the trauma management system. There are two SPIs for roads, namely the road network SPI and the road design SPI. The road network SPI indicates whether the actual road category is appropriate given the urban areas that it connects. The road design SPI determines the level of safety of the existing roads.

For the calculation of the road network SPI, the following information is required:

- Location of urban centres
- Number of inhabitants per urban centres
- Location of roads that connect centres
- Road categories of actual roads (expressed in AAA to C)
- Length of roads

For the calculation of the road design SPI, the following information is required:

- EuroRAP Road Protection Score (RPS) per road segment or route
- Road length per road segment or route
- Road category of the current network

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

Classes or values used for scoring each road characteristics to obtain the RPS during drive-through inspections (Source EuroRAP as reported in SafetyNet, 2007a).

SPIs for road network and road design were evaluated in Netherlands (SafetyNet, 2007a) and the investigators found that it seemed possible to automate the process of the calculation of the network SPI. Moreover, most of the data necessary for the calculation of the network SPI was available in a geographical database. The process of calculating the network SPI is however quite complex and a large amount of data is needed (also in case of a sample). For the calculation of the road design SPI, EuroRAP Road Protection Scores (RPS) for individual road segments or routes are needed.

The investigators concluded that SPIs provided insights into the safety quality of the network as a whole and of individual roads and that application of these SPIs to assess the safety of the network is recommended taking the following into account;

- SPIs only assess the safety performance of rural roads and motorways. Extension and adaptation of the method in the future in order to include urban roads as well is recommended.
- The precise methodology by which EuroRAP calculates RPS scores on the basis of values on various road characteristics is not yet published. It is important to publish these details for better understanding and assessment.
- More detailed evaluation of the results is recommended

SafetyNet (2007b) reported on macroscopic data concern the CARE (Community Road Accident) data-base. This database stored road-user related accidents from all EU-member since 1990. Accidents can be characterised by the regions and the countries they took place in and also the point in time (e.g., the year, the month) when they happened. This data-base offers a wealth of information on each accident and can therefore be aggregated in very different ways, tailored to the particular road safety aspect that needs to be addressed (e.g., county, region, road-type, accident type, vehicle type, participant type, etc.). The research question can be very broad (e.g. did the fatalities in a particular country decrease at the same rate as those in other countries?) or very specific (e.g., did a particular junction become safer after reconstruction?). *Multilevel analyses* allow for the introduction of exposure data and data about safety performance indicators, even if those are not specified at the same level of disaggregation as the accident data themselves. In this way, multilevel analyses allow a global and detailed approach simultaneously. *Time series analyses* allow describing the development over time, relating the accident-occurrences to explanatory factors such as exposure measures or safety-performance indicators (e.g. speeding, seatbelt-use, alcohol, etc), and forecasting the development into the near future.

Microscopic analyses (addressing questions like, did the type of baby-seat affect the risk of young children being killed in an accident?) require in-depth accident data and allow detailed analyses of factors that contribute to the severity of injuries. This type of data involves a high level of detail and is inherently structured in a hierarchical way describing the accident process (persons are nested into vehicles; vehicles are nested into accidents, etc.) Moreover, accidents can be clustered according to geographical or administrative units. In-depth accident data therefore readily call for detailed multilevel analysis.

Multilevel modeling and time series analyses form two powerful tools that can help researchers analysing complex data structures that violate the assumptions posed by traditional analyses. A number of empirical examples demonstrated that many (if not most) data sets in traffic safety research are hierarchically structured and/or form a time-series. Multilevel modeling and time series analysis allow the proper representation of the hierarchical structure of data and their development over time. This representation is crucial to answer questions about these structures themselves, and forms the basis for a proper investigation of possible other factors, allowing experts in road safety to identify different kinds of risk factors and to propose effective and objective policy decisions.

2.20 Road Infrastructure Safety Assessment (New Zealand)

Appleton et al. (2009) describe an evidential based system for assessing the road engineering features that impact on the safety of roads. They report that the purposes of Road Infrastructure Safety Assessment (RISA) are to:

- Provide Land Transport NZ with an objective measurement of Road Controlling Authorities' (RCAs') performance with respect to road safety
- Assist RCAs with a tool to improve road safety through engineering by identifying the features that make the greatest contribution to road safety.

The forerunner to RISA was Safety Auditing of Existing Roads (SAER) based on physical inspection and 40 audits were carried out between 1995 and 2002. They reviewed this manual approach and concluded:

- That generally using a different sample of roads, both audit teams came to the same general conclusion regarding the safety performance of the road network being audited namely, that the roads in the District were generally in good condition.
- That approximately 35% of all issues identified were commonly identified by both teams.
- Each audit team assessed Risk Level Ratings slightly differently for issues commonly identified in both reports.

The key elements required for an improved system, were identified as; the inclusion of relative risk data, exposure length, terrain type and traffic volume. Relative risk quantifies the risk associated with the presence of a particular infrastructure feature, for example, a deep drain next to the carriageway.

At this stage of the development of RISA risk factors and assessment processes have only been developed for rural roads and the current methodology is still undergoing trial and validation. Initial trials were undertaken on a limited number of road sections and the method was modified and used for 'trial assessments' of four RCAs. These trials used field sheets for recording the required features and then down loaded them to spread sheets which were set up to apply the various 'Risk' factors that the research had identified. To assist with the recording of the features and to achieve as higher level of consistency as possible interpretation survey guides have been developed and modified as experience has been gained. Whilst there is an incentive to be able to provide an overall 'Risk Rating' for an RCA the difference in accident rates between 'intersections' and 'mid block sections' it is not reasonable to amalgamate the 'Risk' scores for these two aspects of road infrastructure. They are therefore reported separately.

The basis of the RISA system is a two-stage methodology involving physical inspection and desktop analysis. The first stage involves comparing the safety performance of a road section against a reference road section. The presence and/or absence of various road features are identified relative to the selected reference using the field recording sheets and interpretation guides. This reference road does not necessarily have features that currently comply with guidelines and standards used in New Zealand. This reference road serves only as a baseline and is derived from the research of the crash data and the effects of various road geometry and roadside features on crash potential and severity.

Survey Method and Team Dynamics

A team of three assessors and a driver is required to carry out an assessment and collect all the necessary data. Experience has shown that some locations within the survey vehicle for various tasks are better than others. The survey is completed by driving a 5 km section of road in both directions at the assumed 'normal' operating speed for the road type and alignment. This is repeated but at a slower speed to collect the more detailed information and repeated a fifth time, if necessary, stop and inspects particular features and takes photographs. After the fourth drive-over a brief discussion is held to 'compare notes' and agree on any particular issues. The field recording sheets are all completed and the data input into the risk assignment spread sheets which provide all of the risk ratings for each feature and an overall risk rating for the mid block section. These risk ratings take account of traffic volumes and terrain and road type i.e. flat, rolling, mountainous and low, medium or high volume rural. Intersections are assessed using a similar methodology but only require two assessors.

Data Recording and Assessment

An assessment score sheet (field sheet), similar to that presented below, is completed for each section. There are a total of 4 field sheets for each road section assessed, each covering a specific group of features under the broad headings - Cross Section; Surface; Alignment; Intersections. The purpose of the physical assessment is to identify the presence or absence of individual features and to assess the approximate exposure length of each feature and distance from the road carriageway edge if appropriate. For example, the reference road has a certain shoulder width. The RISA field sheets are used to record the length of road where the shoulder width fell above or below those reference values.

RCA Assessment	Your Name	Date	Road Name	Start	End	Terrain	AADT	Length

CROSS SECTION

Item		0	1	2	3	4	5	Exposure Lgth (km)	Relative Risk
One Lane Bridge w/warning (BEM)									60
One Lane Bridge w/out warning									80
Hazards within 6m	Point								20
	Recoverable length								10
	Non-recoverable length								15
Unsealed Shoulder									5
Shoulder width	Very wide (only RT 1)								-20
	Wide (only RTs 1,2)								-10
	Narrow (only RTs 2-6)								10
	Very narrow (only RTs 3-6)								20
Lane width	Narrow								10
	Very narrow								20
Lane width	Very narrow								20
	Narrow								10
Shoulder width	Very narrow (only RTs 3-6)								20
	Narrow (only RTs 2-6)								10
	Wide (only RTs 1,2)								-10
	Very wide (only RT 1)								-20
Unsealed Shoulder									5
Hazards within 6m	Non-recoverable length								15
	Recoverable length								10
	Point								20
		5	4	3	2	1	0		

Filed Sheet for Cross section features

Where the shoulder width fell below the reference width a safety dis-benefit will be assigned, where the shoulder width was wider than the reference width, a safety benefit will be assigned. This information is then used to determine a Features Risk Score for each group of features (i.e. each field sheet), based on the sum of the risk scores for each feature. The Features Risk Score has a baseline of ‘1’. For example, a Features Risk Score of 1.2 indicates that there are features on the road section that could be eliminated or modified to reduce the risk to road users by 20%. The combination of the Features Risk Scores for each road becomes the Mid Block Risk Score for the entire section of road assessed. This also relates to the difference in potential accident risk for the road section assessed compared to the baseline.

Understanding Relative Risk

Relative Risk on the field sheets is the percentage accident rate difference identified for the infrastructure item multiplied by 100. Items with negative relative risks improve the safety of a road beyond the road type baseline. “Exposure” is the proportion of the audit section affected by the infrastructure item, measured in kilometres, or in some cases the number of occurrences of an item. The item risk score is the relative risk times the exposure. As a measure of safety performance for a route, RISA sums the risk scores for all items. This sum is expressed as a risk per kilometre, equivalent to the accident rate, by dividing the sum of the item risk scores by 100 and by the route length (usually five kilometres) and added to one. An example calculation is shown below. Using as an example, the risk score for cross section items is 81.25 for the 4 km route.

$$\frac{RiskScore}{SectionLength} = \frac{81.25}{4} = 20.3$$

The risk per kilometre is expressed relative to 1.0

$$= 1 + \frac{20.3}{100}$$

This value is the Feature Risk Score for cross section risk. A road that has the same characteristics as the baseline will have a risk of 1.0. In this example the road has a 20.3% higher risk rate per kilometre for cross section items than the baseline. Similar field sheets for alignment, and surface items are completed in the same way. The risks per kilometre are combined for the three field sheets to get a Mid-Block Score. The intersection items are assessed in a similar way to get an Intersection Score. To illustrate consider the above example. Assuming the alignment and surface risks are 1.1 and 1.15 respectively, the Mid-Block Risk Score is 1.453.

Analysis & Factoring for Road Type, Terrain and Use

To develop an overall measure of road infrastructure safety provision it is necessary to adjust the Mid Block Risk Score to account for Road Type, Terrain Type and Traffic Volume. The derivation of Road Type and Terrain Factors comes from existing literature including the Transfund Project Evaluation Manual and the Transit Geometric Design Guide draft version. The resultant score is the Factored Risk Score and because of its 'exposure' component, provides for the best overall measure of safety performance. This basis therefore results in a higher Factored Risk Score being assigned to roads with higher volumes but similar features thus suggesting to the road managers that attention is best paid to the roads with higher Factored Risk Scores rather than perhaps a higher risk item on a low volume road. Continuing the example above suppose the terrain is flat and the traffic volume is 650 vehicles per day. The terrain factor is 1.0, the road type is 'low volume rural' and the road type factor is 1.6. The traffic volume factor is the traffic volume divided by 1000 is 0.65.

Factored Risk Score

Mid Block Risk Score X Road Type X Terrain Type X Traffic volume

= 1.453 X 1.6 X 1.0 X 0.65

= 1.51

The Factored Risk Score has no absolute meaning and is used for comparative purposes only.

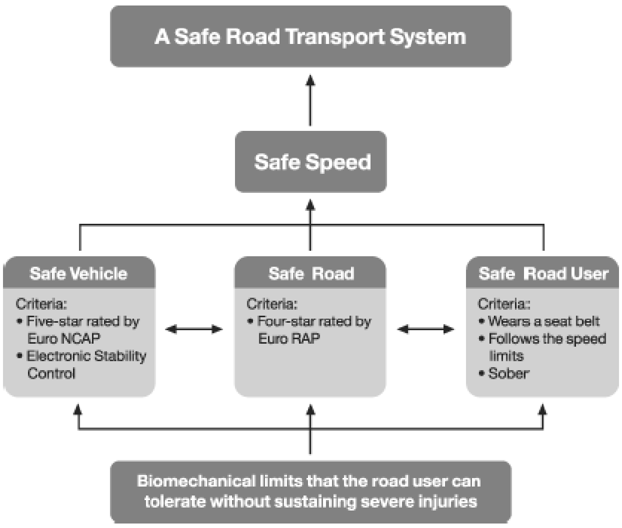
Trial Results and Improvements

Assessment reports of four RCAs have been completed and the following is a list of the main risk factors identified using this methodology

- Poor sight distances at intersections and/or inappropriate type of control installed. (Stop or Give Way)
- Poor quality maintenance of edge marker posts particularly the replacement of missing posts.
- Lack of edge marker posts in the vicinity of sub standard vertical curves.
- The presence of reticulation poles to close to carriageways.
- The presence of trees on road reserve.
- Some areas of poor pavement maintenance including edge break, pot holes and uneven surface.
- Deep side drains to close to the carriageway.
- Several vertical curves with substandard sight distance.
- Bridges with poor end protection

2.21 Swedish Road Administration Safe Road Transport System Model

Stigson et al., (2008) report on the interaction between the different components of the road transport system, such as vehicles, roads, the roadside area, and road users, is important. Most crashes are linked to human factors, and a sustainable transport system needs to address this fact in the same way as occupational injury is handled and seen as a system control problem. A safe system should be designed to minimize the consequences in unforgiving situations instead of focus elimination of human errors. Most types of accidents are judged to be human error and, according to Rasmussen (1997), to look at accidents in terms of event is not so useful to make improvements of the system. There is a common understanding of not only important risk variables associated with serious road crashes but also associated safety indicators. The safety indicators mentioned are related to vehicle, infrastructure, seat belt use, speed, and soberness. The Swedish Road Administration (SRA) introduced a model for a safe road transport system, where these safety indicators have been linked to each other and criteria have been defined (Linnskog, 2007). In this way, deviation from the fulfilment of these criteria could be seen as noncompliance. The definition of a safe road transport system in the model, based on biomechanical limits that human beings can tolerate without sustaining severe injuries, is that the driver uses a seat belt, does not exceed the speed limits, and is sober; the vehicle has a five-star rating by Euro NCAP (European New Car Assessment Programme); and the road has a four-star rating by EuroRAP (European Road Assessment Programme).



SRA Model for safe road transport

The capacity of the system for injury mitigation is determined by the safety standard of the vehicle and road. The primary role of the road is to assist in the reduction of crash energy and to help the vehicle to maximize its inherent safety protection design. Speed limits play a fundamental role in the model; e.g., the safety level of the road must increase if the speed limit increases. In the SRA model, the criteria for the road are based on the EuroRAP Road Protection Score (RPS), a rating score that considers road factors in user protection from fatal or serious injuries (EuroRAP, 2007). The RPS ranges from 1 to 4, where 4 is the rating for a high road safety standard, giving a relatively low risk rating for fatal and serious injuries. The RPS is based on data gathered from real-world crashes and crash tests correlated to survivable limits. Brude and Bjorketun (2006) have validated the RPS and found that the star rating corresponded well with real life data: the higher the star rating, the fewer the car crashes with serious and fatal injuries. Figure below describes the requirements for a road to achieve a four-star rating.

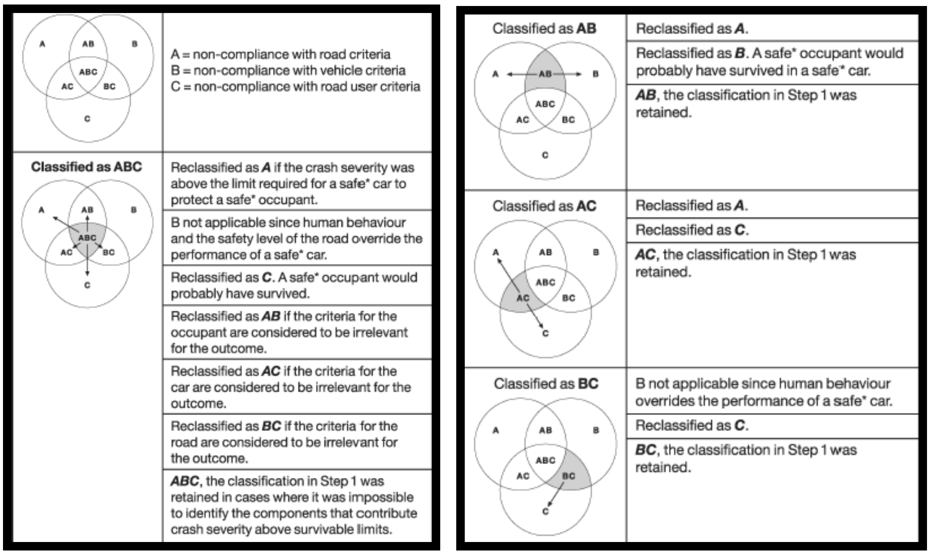
Head-on collisions
≤ 70 km/h safe speed limit
>70 km/h separated lanes required
Run-off-the-road collisions
≤ 50 km/h safe speed limit
≤ 70 km/h guard-rail or safety zone >4 m required
>70 km/h guard-rail or safety zone >10 m required
Collisions at intersections
≤ 50 km/h safe speed limit
>50 km/h grade separated or roundabout required

Criterion for the 4-star rating in SRA Safe Transport Model (after Stigson, 2008)

The criteria for a four-star road are mainly focuses on the road's protection capacity for three different crash types: head-on crashes, run-off-the-road, and crashes at intersections. The total road star rating is summarized by a weighting factor based on the distribution of these three crash types. The definition of a safe vehicle in the model is that the vehicle should have been awarded a five-star rating in a Euro NCAP crash test (Euro NCAP, 2007) and should be fitted with Electronic Stability Control (ESC), since ESC has been shown to effectively reduce the risk of crash involvement (Ferguson, 2007).

For the current study, analyses began at the stage where a crash had occurred and focused on finding the reason for the fatal injury outcome, not the reason why the crash occurred. This could be due to one component or a combination of all three components of the system: the road, the vehicle, and/or the road user. To evaluate whether it is possible to use the SRA model to identify weaknesses in the transport system, real-life crashes with fatal outcomes were classified and adapted to the model criteria However, some factors were added to the SRA criteria. Instead of using the EuroRAP RPS for the total road route, as described in the introduction, a crash scene rating was made, based on the spot where the crash occurred. The crashworthiness of the road was classified according to the type of central reservation, roadside area, and intersection, in order to highlight the local risk of the crash and how these three components influenced crash outcome.

The classification was made in two steps, based on the following questions:
Step 1) Were the criteria in the SRA model fulfilled or not?
Step 2) In crashes where more than one of the three components is noncompliance with the safety criteria, are all components correlated to the fatal outcome?



Principles used to determine the reason for fatal injury

All fatal crashes where a car occupant was killed that occurred on public roads in Sweden during 2004 were included: 215 crashes in all, with 248 fatalities. In total, 205 passenger cars, 5 sports utility vehicles (SUV), and 5 multi-purpose vehicles (MPV) were included in this study. Crashes suspected to be suicide were excluded. well as both belted and unbelted occupants, were included in this study. The material was divided into four different groups: single-vehicle crashes (116 fatalities), head-on crashes (80 fatalities), crashes at intersections (34 fatalities) and “other” (18 fatalities), including vehicle–animal crashes, rear-end crashes, and multiple crashes.

It was possible to classify 93% of the in-depth fatal crashes according to the SRA model, and no fatalities occurred when all criteria were fulfilled. The model did not address rear-end or animal collisions or collisions with stationary/parked vehicles or trailers (18 out of 248 cases). In order to identify weaknesses in the road traffic system, a method was developed as a complement to the SRA model, for mapping the cause of fatal outcome. In the presented study, fatal outcomes were mostly related to an interaction between the three components: the road, the vehicle, and the road user. Of the three components, the road was the one that was most often linked to a fatal outcome.

2.22 Rural Road Crash Prediction Project (New Zealand)

Crash prediction models are useful tools for evaluating the crash risk of a section of road, and also for evaluating the benefits of any changes to a road section. The benefits of using these models are recognised internationally and many countries have developed comprehensive crash prediction models of road stereotype models for these purposes. The overall purpose of this project was to quantify the impact of all key road features on the safety of two-lane rural roads, and understand/quantify any interaction between these variables, Turner et al. (2011).

The key objective was to assess different methods of collecting data and to build preliminary crash prediction models that would identify the key variables required for the final models that would be developed during the 'main study' stage. Part of this 'pilot' stage involved data collection and integrated modeling of data on a large number of variable types. These variables were broadly classified into categories such as traffic volume, road geometry, lane width, shoulder environment, roadside hazards, road pavement condition and accesses.

Type	Variable
	Seal Width (m)
	Unsealed Shoulder Width (m)
	Recoverable Slope Width (m)
Shoulder Environment	Traversable Slope Width (m)
	Wood Pole >200mm (no)
	Light Column <300mm (no)
	Concrete Pole – usually 'I' section (no)
	Heavy Street Pole >300mm without slip base (no)
	Signs Supports >120mm without slip base (no)
	Trees - trunk >100mm diameter (no)
	Culverts - road side (no)
	Culverts - road with non-traversable headwall (no)
	High impact roadside furniture (no)
	Non-traversable slope / perpendicular deep drain (m)
	End concrete barrier / bridge parallel to road (m)
Point Hazards	Concrete fence/barrier perpendicular to road (m)

Roadside Hazards (after Turner et al., 2011)

Data was collected on state highways, for which road alignment information was available in an electronic format. Two hundred sections, each of them 400m in length, were randomly sampled from all two-lane sections of state highway in New Zealand.

The predictor variables included in the modeling were checked for correlation to identify pairs of variables that may have a cross-relationship with each other and therefore should not be included together in the models. The following pairs of variables were observed to be significantly correlated:

• Combined point hazards and traversable slope width/distance to non-traversable slope: This supports the suitability of using a combined roadside environment rating, such as the KiwiRAP roadside hazard rating, as opposed to looking at the impact of each element of the roadside environment separately.

• Traffic volume (AADT) and seal width: Both of these variables are recognised to be important from a crash prediction perspective. During the main study, a suitable approach to overcome this correlation may be to define fixed AADT bands and build individual crash models for each of these bands.

• Accesses and number of culverts – roadside: This suggests that accesses on rural roads are often accompanied by drainage culverts. It thus seems reasonable to discard 'culvert – roadside' as one of the predictor variables.

• Combined point hazards and combined accesses were both correlated to the individual categories of point hazards and accesses respectively: This supports the use of the 'combined' variables to describe point hazards and accesses.

• Recoverable slope width and traversable slope width: In the main study, a suitable measure to overcome this correlation may involve modifying the definition of traversable slope to refer only to the slope width starting from the edge of the recoverable slope, instead of from the edge of the seal.

The modeling methodology adopted in this study was in accordance with the approach made in many previous studies, and involved fitting generalised regression curves to independent and dependent data. Traffic volume (AADT) was included as a default variable in all the crash models. Starting with the single-variable volume-only model, additional variables were added to assess the best-performing sets of variables. From the initial list of 28 variables for which data (both manual and electronic) was collected, a most-representative and best-performing set of eight was selected to be incorporated into the multi-variable models alongside traffic volume, based on the results of the two-variable models. The variables that were found to perform the best are listed in the table below.

Type	Variable
Traffic volume	Traffic volume (V)
Shoulder environment	Unsealed shoulder (U)
	Seal width (S)
Point hazards	Combined point hazards (H)
Accesses	Combined accesses (Ca)
Roadside – other	Distance to non-traversable slope/perpendicular deep drain (N)
Road geometry	Absolute curvature (C)
	Absolute gradient (G)
	Skid resistance (Sr)
	% reduction in curve speed (Vc) [1]

Variables in multi-variable models

The results of the two-variable models indicated that horizontal geometry was not a significant variable. However, horizontal geometry is widely considered to have a significant effect on crash rate. A horizontal alignment variable (percentage reduction in curve-negotiation speed of the section compared with the preceding 500m section) was thus later introduced into the best-performing four-, five- and six-variable models.

4-variable model	5-variable model	6-variable model
Traffic volume (V)	Traffic volume (V)	Traffic volume (V)
Distance to non-traversable slope/perpendicular deep drain (N)	Distance to non-traversable slope/perpendicular deep drain (N)	Distance to non-traversable slope/perpendicular deep drain (N)
Skid resistance (Sr)	Skid resistance (Sr)	Skid resistance (Sr)
Absolute gradient (C)	Absolute gradient (C)	Absolute gradient (C)
	Combined accesses (Ca)	Combined accesses (Ca)
		Combined point hazards (H)

Factors used for multivariable modeling

The best-performing four-, five- and six-variable models shown in above table do not contain a road geometry variable, which is considered to be important from a crash-risk perspective. The horizontal alignment variable (percentage reduction in curve speed, Vc) was thus added to the above best-performing models, so that horizontal geometry could be given consideration in the final model form. The overall preferred model (5-variable Model) was found to involve volume, distance to non-traversable hazard, absolute gradient, SCRIM coefficient, and percentage reduction in curve speed. The preferred model had the following form:

$$A = 2.2E^{-04}\ V^{0.719}\ x\ N^{0.078}\ x\ G^{-0.26}\ x\ Sr^{-2.569}\ x\ Vc^{0.219}$$

where:

A: is the predicted number of crashes in five years for a 100m section of rural road

V: is the two-way AADT for the road section

N: is the distance in metres to the non-traversable hazard (e.g. row of trees or deep ditch), multiplied by 1000.

G: is the absolute gradient

Sr: is the average value of SCRIM for the road section

Vc: is the percentage reduction in the curve-negotiation speed of the section as compared with the preceding 500m section

This study has built upon the main recommendations of the 'Scoping report' (from stage 1 of this research) and includes the key predictor variables and sampling methodology identified therein to build initial crash models. The key recommendations for the 'main study phase' of this research, based on the research outcomes of this pilot study, are as follows:

• It may be beneficial to undertake data collection and analysis for homogeneous elements of varying lengths on the state highway network, instead of on fixed section lengths. However, because of inaccuracies in crash location data, both homogeneous road lengths and road elements should be considered during the main study.

• The low density of accesses on a large proportion of sections in the sample set suggests that it may be viable to use a generic figure of 0.5 accesses per 100m for a majority of road sections. Data collection may only be required for state highways in areas that are known to have a high or very low density of access-ways.

• There is ample support for the use of the KiwiRAP roadside hazard rating to estimate the quality of the roadside environment. The use of this rating will eliminate correlations between predictor variables as mentioned earlier, while at the same time providing a reasonably detailed and large sample set of data for building the models.

• It may be necessary to build separate crash models for individual AADT bands, to eliminate the correlation between AADT and seal width. Such a model form will also help to better estimate the safety benefits of seal widening.

2.23 FHWA's IHSDM

The Interactive Highway Safety Design Model (IHSDM) Crash Prediction Model (CPM) has been developed for rural two-lane two-way highways (FHWA, 2010). These highways include rural two-lane two-way highways with center two-way left-turn lanes or added passing lanes, and rural two-lane two-way highways containing short sections of rural four-lane highway to increase passing opportunities. Crash prediction models for roadway segments and at-grade intersections of Rural Two-Lane highways are composed of two analytical components: safety performance functions (SPFs) or baseline models and crash modification factors (CMFs). There are also calibration factors that adjust the predictions to a particular jurisdiction or geographical area. There are quite stringent requirements for input data and model calibration. All types of crashes involving vehicles of all types, bicycles, and pedestrians are included, with the exception of crashes between bicycles and pedestrians. The CPM can be calibrated to reflect the safety conditions on the rural two-lane two-way highways operated by a particular highway agency. The Empirical Bayes (EB) method is incorporated in the algorithms used in crash prediction.

The general form of the crash prediction models for roadway segments is shown in the equation below

$N_{rs} = C_r\ N_{spf\text{-}rs}(CMF_{1r}...CMF_{nr})$ **(3.1)**

where:

N_{rs}= predicted number of crashes for roadway segment per year

$N_{spf\text{-}rs}$ = predicted number of roadway segment crashes per year for nominal or baseline conditions;

C_r = Calibration factor for roadway segments developed for use for a particular jurisdiction or geographical area;

CMF_{nr} = crash modification factors for roadway segments.

The general form of the crash prediction models for intersections is shown in the equation below:

$N_{int} = C_i\ N_{spf\text{-}int}(CMF_{1i}...CMF_{ni})$

where:

Nint= predicted number of crashes for intersection per year;

$N_{spf\text{-}int}$ = predicted number of roadway segment crashes per year for nominal or baseline conditions;

C_i = Calibration factor for intersection developed for use for a particular jurisdiction or geographical area

CMFni = crash modification factors for intersections.

There is one model for highway segments and different models for the three types of intersections mentioned before. Crash severities studied in the models are of types Fatal and Injury (FI) and Property Damage Only (PDO).

2.24 Finland TARVA

Peltola (2009) describes the TARVA system developed in Finland in 1993 to evaluate road safety and safety effect. TARVA is a tool for evaluating safety effects of road improvements and uses the Empirical Bayesian method to evaluate the current safety situation to make safety effect estimates reliable. This approach enables a better understanding of accident prone locations as well as the various possibilities to enhance traffic safety cost-effectively. TARVA combines information about accident history with the accident model information to evaluate current safety situation. Secondly, the outputs coefficients are used to evaluate the safety impacts due to one or several simultaneous improvements. Thirdly, the severity of accidents is taken into consideration to evaluate the effects on fatalities. This evaluation can be applied to the whole national road network. Data relating to accidents, traffic and road data recorded by Finnish Road Authorities in detailed in table below.

Accident data	**Traffic data**	**Road data**
time and location	AADT, cars	pavement width
consequences	AADT, heavy vehicles	curviness
accident type	vehicles entering junctions	hilliness
		sight distances
		speed limit
		urban areas nearby

Sample data inputs used in TARVA (after Peltola, 2009)

The biggest problems in modelling data are caused by missing flow data for unprotected road users and the lack of adequate information of the land use along the road. Although the author points out that using the number of inhabitants near the road in the models solves part of the latter problem. The TARVA-estimation of safety effects of road improvements is a four-phase process;

1) For each homogeneous road segment, the most reliable estimate of the accident number is calculated from the number of accidents in the past, vehicle mileage and the average accident rate in corresponding conditions. Information about accident history and accident model are combined in a formula which takes into consideration the model's goodness of fit and the random variation in the number of accidents. The weight of the accident model compared to the weight of the accident history is the bigger; the more there is random variation in the accident count.
2) To make a prediction of the number of accidents without road improvements, the most reliable estimate of the number of accidents is corrected by the growth coefficient of

the traffic. Also the effects of fundamental changes in land use on the predicted accident number can be taken into consideration by the coefficient.

3) The effects of the measures on injury accidents are then described in terms of impact coefficients. The impacts coefficients have been obtained from the research results of all the relevant countries taking into consideration the differences between countries in traffic regulation and road user behaviour. An example from impacts coefficients: building a new roundabout reduces accidents involving vulnerable road users by 15%, has no effect on animal accidents and reduces vehicle-only accidents by 50%. The effects of several simultaneous road improvements are evaluated so, that overlapping measures are properly taken into account.
4) Road improvement measures can also affect the severity of the accidents remaining on the road after the improvement. These effects can also be taken into consideration in TARVA by using severity change coefficients. Using the evaluated injury accident reduction percentage and knowledge on the average severity (deaths/100 injury accidents) and its change, TARVA gives an estimate of yearly-avoided fatalities. An example from severity change coefficients: building a new roundabout reduces the severity of accidents including vulnerable road users by 30%, has no effect on the severity of animal accidents and reduces the severity of vehicle-only accidents by 50 %.

Conclusions:

- The number of accidents during one year cannot be predicted accurately. Hence it is difficult to make conclusions from accident data for one year when trying to identify hazardous road sections.

- Motor vehicle mileage explains most of the variation of motor vehicle accidents. Adding more explaining variables does not improve the model very much. One of the main reasons for this is that the accident models were computed for homogenous group of road sections.

- One can conclude that you can use quite simple accident models when estimating the expected number of accidents on a particular road section. To understand and illustrate the relationships between traffic and road conditions and the expected number of accidents, you probably need more complicated models.

- In practice this means that reliable estimates of exposure are necessary for developing good accident models.

2.25 Summary

Contemporary research can be broadly categorised under four headings; Research Topic, Road Accident Scenarios, Road Safety Risk Methodology as well as positive and negatives aspects in relation to EuRSI, Table 1.

Factors reported in various studies include road geometry, driver characteristics, AADT, surface condition, hazards, existing road safety features as well as historic accident database. Modelling approaches were broadly based around Linear Regression and Bayesian models. One of the challenges in constructing risk models for road network is that multiple factors based around the various complex interactions of driver, vehicle and road environment are usually involved and some of these can be very difficult to identify and model. Historically, research has approached this challenge by adopting a global or more scenario specific approach.

The global approach attempts to construct a global model based around global factors that are readily accessible such as historic accident, AADT, and road length. These models can deliver a general synoptic safety performance overview of the network but the reduced number of input factor together with inherent coarse spatial-temporal granularity results in a generalised snapshot of the network that is are far from comprehensive. On the other hands, risk assessment models have been constructed based around specific factors, addressing a specific potential safety risk scenario e.g. transition curves or intersections on rural roads. These are found to be successful for that road environment and risk scenario but for the same reasons that these are successful make them un-suitable to apply to a global scenario.

The smaller research projects typically address either a single road environment or collision scenario type. However, this is not always the case like Cafiso et al. (2010), who tackles the challenge of separating out factors, computing correlation, and weightings before running these through a variety of risk models. This exercise, although thoroughly comprehensive, comes with a caution from the author in terms of wider application and once again illustrates the complexity of attempting to understand how various factors can be identified and their contribution to universal risk understood.

Project	Road Accident Scenarios	Road Safety Risk Technique	Positive aspects in relation to EuRSI	Negative Aspects in relation to EuRSI
Risk evaluation by modelling of passing behaviour, Farah eta l., 2009	Overtaking manoeuvres on rural roads	Modelling risk relating to overtaking manoeuvre based on road geometry and driver characteristics (ages & gender)	A better understanding to the relationship between road geometry & overtaking behaviour of drivers	Addresses just one collision type scenario
Assessing crash risk on Road Curves, Chen et al., 2007	Collision along curved sections of road	Two techniques: -Model risk based on historic accidents -Statistical analysis based on five contributing factors to accidents which in turn are based around vehicle, driver and environment	A better understanding to the relationship between road Alignment & Accident data model	Addresses just one collision type scenario
Effects of Geometric Design Consistency on Road Safety, Canadian Journal of Civil Engineering	Generic relationship between design consistency and road safety	Generalised Linear Regression used for model development	Generalised Linear Regression Model based on road geometry	Addresses just one collision type scenario
Roadside Point Hazards, Wrusz (2007), Austria	Impact with Trees	Safety Investigation Methodology based on a number of parameters; -Road geometry -Surface condition -Street furniture -Tree to road distance -Tree diameter Environmental information	Initial assessment of point hazards along road-side	Addresses just one collision type scenario
Bayesian hierarchical approach for developing safety performance functions (Ahmed et al., 2011)	Mountainous roads under unique weather conditions	Hierarchical Full Bayesian models were developed to relate crash frequencies with various risk factors associated with adverse weather, road alignments and traffic characteristics	Hierarchical Full Bayesian models for handling multi-variables	Addresses just one crash road environment type scenario
Safety Assessment on Accidents, Traffic Flow and Facilities (Wang et al., 2008)	Rural freeways	Safety performance index based around accidents, road features and traffic	Safety Performance index	Global Model
5-level Roadside Hazardousness Index (Pardillo-Mayora et al., 2010)	Run off road accidents	5-level Roadside Hazardousness Index (RHI) • roadside slope degrees, non-traversable obstacles offset from the roadway edge, • safety barrier installation, and highway alignment	Roadside Hazardousness Index	Addresses just one collision type scenario
Road Safety Framework (Yildiz & Hauger 2009)	Road Safety Inspections	Dividing roads into sections based on active & passive hazards identified during an RSI	Road sub-division based around hazards that are sub-classified according to causative and severity index	Addresses limited number of causative risk factors
Comprehensive Accident Model for Rural Roads Cafiso et al. (2010)	Generalised risk model	Model risk based on exposure, geometry and various consistency & context variables directly related to safety performance Data Collections based on GPS based surveys & road inspection to record other road characteristics Various models considered using a Generalised Linear Modelling	In-depth examination of risk factors, correlation, and contribution to accidents tested using various models	Illustrates the challenges in attempting to calculate universal risk factors, weightings and outcomes for any rural road

Project	Road Accident Scenarios	Road Safety Risk Technique	Positive aspects in relation to EuRSI	Negative Aspects in relation to EuRSI
		approach. Some models use only length and traffic flow. Other models produce more detailed results based on significant variables relating to exposure, geometry, consistency and context factors 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).		
Web GIs for Road Risk Analysis	Road Networks	Historic accident data & road length, 50m sampling	Illustrates the advantage of online portal enabling multidisciplinary safety risk assessment collaboration	Global Model for simplified Hazard and Risk models
EuroRAP	Vehicular Collisions: -Run-off-Road -Head-on -Intersection	GPS based Drive-through & Video Survey Road Inspection. Classification of road network and road side features Star Ratings (Network, Accidents, Traffic Flow) Road Protection Score (RPS) detailing how well drivers are protected by infrastructural elements from death or serious injury Computation of a Risk Matrix from combined Likelihood & Severity Rating	Field based data acquisition system Widely used across Europe	Modelling details not published Not all static road risk factors are collected Protocols only apply to three accident scenarios Risk maps are classified along 20km – 30km long sections and so give rise to a degree of un-certainty RPS are produced for 100m sections of road network
Road Safety Assessment in Australian Road Research Board	Generic risk assessment of roads and intersections based around Road Safety Audits	Safety Performance of road environment (mid-block & intersections): -Road Geometry -Overtaking assessment -Road Safety Interventions -Lighting -Skid Resistance -Pedestrian Walkways -Intersections Video Survey Assignment of Risk Score based on key engineering features and roadside conditions Computation of Safety Performance Safety Intervention high-lighted	Field based data acquisition system Outputs included; -Network risk score summary -Risk maps -Risk Score distribution & safety issues -Key safety elements that have an effect on road safety	Not all static road risk factors are considered. Computation of risk factors and their respective contribution at any given location not clear
RANKERS	Safety Analysis on all	Road Safety Index calculation	Field based data acquisition	Computation of risk factors

Project	Road Accident Scenarios	Road Safety Risk Technique	Positive aspects in relation to EuRSI	Negative Aspects in relation to EuRSI
	existing road networks; -Road Alignment -Road Accesses -Overtaking -Roadside Geometry -Pavement Condition -Road layout		system records road geometry, surface condition, safety interventions	and their respective contribution at any given location not clear
SunFlowerNext	Existing Road networks	Road Safety, Policy & Implementation Performance Index	Composite Road Safety Performance Index	Very High level, little detail
IASP	Two lane rural roads	Safety Index based around exposure, accident frequency, & severity	Calculate a Safety Index; Likelihood, Severity, Exposure	Computation of risk factors and their respective contribution at any given location not clear
SafeSPOT	Existing Road networks	Focused on intelligent vehicle and roads for collision avoidance	Highlights the future role of ITS (V2V, V2I) in road safety along rural road networks	Absence of risk assessment in the context of RSI
RIPCORD-ISEREST	Single carriageway rural roads	Best practice for; • Road Safety Impact Assessment tools and Accident Prediction Models • Road Design and Road Environment • Road Safety Audit • Road Safety Inspection • Black Spot Management and Safety Analysis of Road Network	Comprehensive series of investigation covering all aspects of road infrastructure safety measures. Excellent reference for EuRSI.	Lacks any linkage of Risk Assessment within the context of a RSI
European Road Safety Observatory	All Roads	Safety Performance Indicators (SPI) for road network and road design SafetyNet for Community Road Accident (CARE)	A number of studies including safety performance indicators SPI and multilevel analyses based on accident databases	Uses EuroRAP and risk modelling is global in nature
Road Infrastructure Safety Assessment (New Zealand)	Mostly rural road Networks	Assessment of each section under 4 broad headings Cross Section; Surface; Alignment; Intersections Determine a feature risk score based on sum of risk scores of all features within the section Items with negative relative risk improve safety Produce a mid-block risk score which is then adjusted for road type, terrain and traffic volume	Risk assessment field based, reasonable comprehensive factor assessment	Data collection is manual. Computation of risk factors and their respective contribution at any given location not clear
Swedish Road Administration (SRA) Safe Road Transport System Model	Road Networks	SRA model based around EuroRAP RPS adapted by using crashworthiness of the road was classified according to the type of central reservation, roadside area, and intersection, in order to highlight the local risk of the crash and how these three components influenced crash outcome. Fatal injuries were closely examined to determine non-compliance/compliance with driver, vehicle, road criteria	An operational national system based on EuroRAP RPS & historic accidents to identify causative factors and improve outcomes	Uses EuroRAP and a global model targeting the entire ational network

Project	Road Accident Scenarios	Road Safety Risk Technique	Positive aspects in relation to EuRSI	Negative Aspects in relation to EuRSI
Rural Road Crash Prediction (NZ)	Quantify the impact of all key road features on the safety of two-lane rural roads, and understand & quantify any interaction between these variables	A number of models based around Linear Regression analysis	Linear Regression Models based around five road factors; volume, distance to non-traversable hazard, absolute gradient, SCRIM coefficient, and percentage reduction in curve speed	Some caution is advised since the authors state that this model was developed and tested using a relatively small sample size and so, not suitable for general use.
FHWA's IHSDM	Rural Road Networks	Empirical Bayesian based algorithm incorporating model parameter calibration. Data requirements include geometric design, traffic flow, control and accident data	Comprehensive modelling approach	Detailed Data requirements and a reasonable high work load to calculate parameters and coefficients (e.g. 12 sets) before computing various crash prediction scenarios
TARVA Finland	Rural Road Networks	Empirical Bayesian algorithm using data relating to accidents, traffic flow and road environment	Reasonable modelling approach that attempts to use data from accident, traffic and road geometry	Accident data is not conclusive in determining hazardous road sections Motor vehicle mileage explains most of the variation of motor vehicle accidents More complicated models are required to understand the relationship between traffic, road environment and potential accidents Reliable estimates for all road sections are required for developing good accident models

Table 1. Summary of road safety risk assessment projects

The larger research projects can be divided in two sub-groups, the first are international research projects that can be used to support policy. These projects provide crucial reference informationregarding various aspects of risk assessment. Examples include SunFlower, Rankers, IASP, Ripcord & European Road Safety Observatory. It is worth noting RIPCORD‘s conclusions in realtion to the shortcomings of accident prediction modelling not only in terms of data availability but also in modelling and subsequent usage. The second sub-group are made up of national initiatives that attempt to construct a universal safety risk assessment solution that cane employed in an operational environment in order to help network managers identify sections of road that require much closer attention. Examples include EuroRAP, ARRB Road Safety Audit (Australia), SRA Safe Road model (Sweden), FHWA, IHSDM-CPM and TARVA (Finland). The range and detail in data inputs has increased and generally includes not only accident data and traffic flow but increasingly more comprehensive data on road environment. These projects can also be categorised by the overall objective of finding a pragmatic solution that although far from perfect are, nevertheless, a step in the right direction and also can be implemented within an operational road network management working environment.

Some of the main findings of this review include

- Modelling risk along roads has generally revolved around deriving a generalised risk rating for an entire network or where a small number of collision type scenarios are considered or a particular road environment is investigated. Exceptions include the comprehensive FHWA’s IHSDM crash prediction module which is a comprehensive, detailed system but requires a reasonable amount of time to collate data and compute various factor parameters and coefficients before running various crash prediction models.
- Identifying risk factors and their respective contributions (parameters, coefficients, weightings) to an accident is non-trivial
- A number of statistical modelling approaches have evolved and can classified into two broad groups; global based around a small number of historic facts such as accidents, AADT, & network length and scenario/location specific where either a collision type or stretch of road is examined in detail. With scenario/location specific modelling more data sources are used and models can become quite complex but still are limited since the resulting model is generally calibrated for that specific scenario or environment.
- National road network managers require pragmatic solutions that although may be lacking in different respects, nevertheless, enable a better understanding of sources of risk along their roads

- Data collection methods of static road environment are steadily improving with advent of GPS and Mobile Mapping Systems. The bottle neck currently is devising suitable analysis and modelling methodologies to transform these data into useful safety risk information in a timely and cost-effective manner.

3 Understanding the factors and data sources that are relevant to assessing risk within the context of Road Safety Inspection

3.1 Introduction

In the preceding Chapter, a review, of contemporary research and best practice in terms of risk assessment within the context of RSI, was carried out. This study highlighted a number of issues relating to complexity of determining risk factors and associated approaches to modelling. The overall objective of this report, detailed in Chapter 1, is ***to formulate a road safety risk assessment methodology to highlight locations and sections along rural road network that require safety interventions based on information acquired during RSI and any other relevant information***. Any accident can result from the complex interaction of various events attributed to the road environment, the vehicle and driver behaviour. EuRSI is concerned with events or factors that are primarily associated with the road environment and in this study focuses on a number of key static road factors including road geometry, surface condition and hazards. This Chapter attempts to describe and understand not only these factors but also the role of other relevant data sources, namely, historic accidents and vehicular speed in computing risk along rural roads.

3.2 Road Geometry

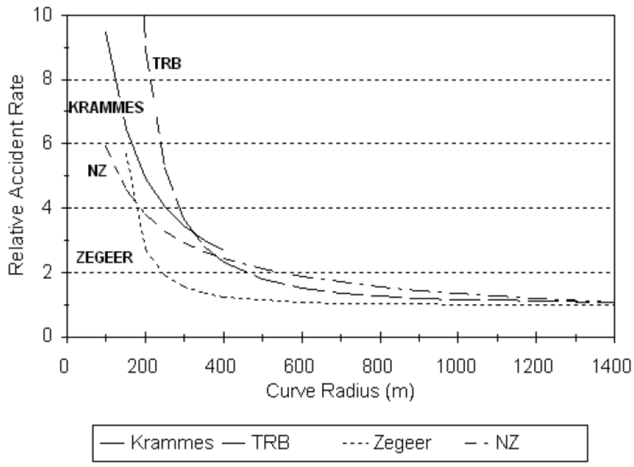
The geometry of any road is fundamental to the safety of road users. A vast array of research has been completed on various factors relating to road geometry, which if treated in isolation in this literature review, would present a prohibitively large number of sources. The approach adopted here is therefore to make use of a number of dedicated and in some cases exhaustive literature reviews already completed, which aim to derive typical relationships between road safety and geometric factors.

3.2.1 Horizontal Alignment

McClean *et al.* (2010) have completed an extensive review of literature associated with crash risk and road geometry as part of Austroads' strategic research program into Road Safety Engineering Risk Assessment. Their review of literature associated with horizontal curves included studies on over 10,000 curved sites in the USA and New Zealand. They concluded that the there were two main forms of accident risk model in the literature:

- A two term relation with accident risk decreasing with increasing horizontal radius of curvature, *R,* and decreasing with increasing curve length; and
- A single term relation with crash risk decreasing with increasing radius of curvature.

It is important to note that other factors such as road environment type (e.g. urban, rural), vehicle velocity have to be taken into account when assessing risk associated with alignment. They re-present a comparative figure from an earlier study (McClean, 1996), shown in the figure below which summarises the relationship between accident risk and horizontal curvature. This suggests for the main that the critical radius, i.e. the radius below which accident risk increases sharply, is approximately 400m.



The relationship between accident risk and horizontal radius of curvature *R* (McClean, 1996)

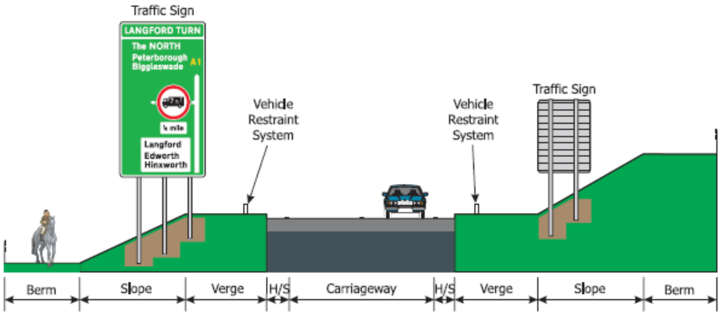
McClean *et al.* (2010) continue to critically assess the data and suggest that:

- Decline in accident risk with increasing curve length may be overstated in the TRB's studies; and
- The increased accident risk at low radius curves may be due to the fact that the TRB sample includes lots of 'isolated curves' (i.e. those with independent tangents preceding them).

According to McClean *et al.* (2010), a horizontal curve with *R* > 1300m can be regarded as the standard against which other curves can be assessed, and is therefore afforded a 'relative risk ratio' of 1.0. In all studies of horizontal curves, it is apparent that an improved understanding of the safety risk associated with horizontal curves can be found by considering the nature of the tangent prior to the curve. This focus, on 'design consistency', is recognised separately further in this section and subsequently in section 3.4 associated when considering vehicle speed.

3.2.2 Lane and Shoulder Width

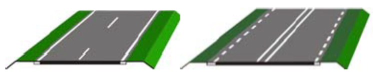
Hard shoulders ('sealed shoulders', or 'hard strips' for narrow hard shoulders in the UK), aside from various maintenance and operational benefits, provide an increased margin of error of drivers and may allow them to regain control of a vehicle before it strikes any roadside hazards. Hard shoulders are therefore particularly effective where run-off-the-road accidents are common. The typical elements of the cross-section of a two-lane rural road are provided in the figure below.



Typical Cross-section of Rural Single-carriageway roads (HA, 2005)

Increased lane widths generally provide increased opportunities for overtaking on single carriageway roads, subject to oncoming traffic. Increased lane widths therefore not only provide a greater margin for error for the driver in run-off-the-road accidents, but also tend to reduce the likelihood of head-on accidents, as drivers are given ample opportunity to overtake slower moving vehicles, including commercial vehicles.

RIPCORD-ISEREST Deliverable D3 (Matena *et al.,* 2007) provides a summary of recommended best practice for the design of European Roads. Rural roads in the context of EuRSI are considered to be analogous to 'Regional/Distributor Roads' identified in this document. The cross-section design standards proposed for this type of road are provided in figure below:

2-lane road		
Cross-section dimension:	11.0-11.4m	
Carriageway with:	8.0/7.5m	
Lane width:	3.5/2.75*m	
Width of emergency lanes:	-	
Width of median:	0/1.1m	
*Small driving lanes only in combination with wide median		

Recommended Cross-Section Design Standards for Rural Roads

Within these measurements, an example of a 1.1m median (created through road markings) is provided in the Netherlands, which results in reduced lane widths. We interpret from the above that a ‘typical’ cross-section may be formed of two 3m lanes, with a 1m hard shoulder.

The rules that underpin the Interactive Highway Safety Design Model (IHSDM) Crash Prediction Module (IHSDM-CPM) detail that a standard reference cross-section for a rural two-lane road is considered to one with lane widths of 3.65m (12ft), with hard shoulders of 1.8m (6ft). Lane widths and hard shoulder widths below this increase risk approximately linearly, with a lane width of 2.7m (9ft) and no sealed shoulder increasing accident risk by 50% (FHWA, 2010). O‘Cinneide et al. (2004) concluded that motorways are seven times safer than undivided two lane roads and three times safer than dual carriageways but only eight times safer than three lane undivided roads.

Carriage Type	Fatal	KSI	All Accidents
Motorway 2 Lane	1	1	1
Dual Carriageway 2 Lane	3	3	3
Three-Lane Undivided	8	8	3
All 2-Lane Undivided	*7*	*9*	*5*
Improved Wide 2 Lane	6	8	4
Improved Standard 2 Lane	9	8	4
Unimproved 2 Lane	6	9	5

Comparison of carriageway type and road accidents (after O‘Cinneide et al., 2004)

Impacts of lane width and hard shoulder width on accidents indicated that widths of 3.25m to 3.50m should be avoided on undivided roads while a lane width 3.0m to 3.75m is optimal for safety. A hard shoulder width of between 2.5m and 3.0m minimised accidents on undivided roads. McClean *et al.* (2010) noted that these typical dimensions in the USA are at the high end of Australian design practice, and chose to adopt a reference case of 3.5m lanes with 1.5m hard shoulder width. Further, they chose to describe the increased risk as a function of total sealed width, rather than identifying the specific individual contribution of lane width and shoulder width separately.

SAFESTAR (2002) was a European research project focussing on traffic safety on the Trans-European Road Network (TERN). As part of this project, a review of design practices was completed across eight participating European countries. They provide information on Danish and German studies that highlight negative or negligible benefit from providing overly wide lanes or hard shoulders respectively. They recommend for single-carriageway roads that lane widths should be 3.5m, with hard shoulders of 1.3m-1.5m.

3.2.3 Vertical Alignment

Vertical alignment is generally considered to have a relatively smaller effect on risk than horizontal alignment. We consider that vertical alignment consists of predominantly two factors: vertical curvature and vertical grade.

Vertical curvature is provided to smoothly transition between different vertical grades. Crest curves (those that transition from positive gradient to negative gradient) are those that present the greatest problems with sight distances and therefore present a risk of head-on-collisions on tangents, and may be hazardous when located in advance of a sharp curve. Desirable minimum crest curves in the UK standard TD9/93 (HA, 1993), are defined so as to provide the desirable minimum stopping sight distance for design speeds above 50km/hr.

Sag curves (providing a transition from negative gradient to positive gradient) pose a lesser problem in respect of sight distance. They may however provide an inherent risk by requiring a long period of deceleration. It is also recognised that sharp sag curves may present a safety risk at night whereby headlights fail to illuminate a sufficient length of road in front of the vehicle. TA85/01 (HA, 2001) notes that high speed differentials occur at crests and sags in the alignment and this can result in increased numbers of accidents particularly where visibility is restricted.

Elvik *et al.* (2009) provides a summary of predominantly European literature on the effect of gradients in accidents. They note that reducing gradients generally reduces the number of accidents, and that the effect of gradients on accidents is more marked at steeper gradients. Table 2 below re-produces their best estimates of accident reduction due to changes in gradient:

Table 2 – Effect of Vertical Gradient Change on Accident Rate (Elvik *et al.,* 2009)

	Percentage Change in Accident Level	
Change in Gradient	Best Estimate	95% Confidence Interval
From >7% to 5-7%	-20	(-38, +1)
From 5-7% to 3-5%	-10	(-20, 0)
From 3-5% to 2-3%	-7	(-15,+5)
From 2-3% to 1-2%	-7	(-12, -1)
From 1-2% to below 1%	-2	(-8, +6)

Whilst TD9/93 (HA, 1993) recommends that vertical grades for single carriageways do not exceed 6%, it also recognises that practically this may not be possible in rural areas, and therefore steeper grades may exist. It does though reference that accident risk progressively increases with increasing vertical grade, and that gradients steeper than 8% (for new roads) should be considered as a ‘departure from standard’.

In developing an accident prediction algorithm that underpins the original IHSDM, Harwood *et al.* (2000) present the effect of vertical grade on accident risk. They conclude that accident risk increases by approximately 1.6% for every percent increase in vertical grade. The latest version of the Engineer's Manual that accompanies the IHSDM (FHWA, 2010), details that the CMF is applied in three bands, shown in Table 3 below.

Table 3 – The effect of Vertical Grade on Accident Rate (FHWA, 2010)

Grade	Crash Modification Factor (CMF)
Level Grade (0% ≤ *G* ≤ 3%)	1.00
Moderate Terrain (3% < *G* ≤ 6%)	1.10
Steep Terrain (*G* > 6%)	1.16

McClean *et al.* (2010) highlight that the AMFs provided by Harwood *et al.* (2000) are not direction-specific and are affected by averaging the effects of increased positive gradients and increased negative gradients. They are applied on the principle that a positive gradient for one direction of travel and a negative gradient for the other direction of travel.

It is accepted in most literature that negative gradients are higher risk than positive gradients. Elvik *et al.* (2009) note that the accident rate on roads with a positive gradient is approximately 7% lower than the accident rate on roads with a negative gradient. Positive gradients however do create some additional risk - largely arising out of the speed differential between light and heavy vehicles (Polidori *et al.,* 2011).

3.2.4 Cross-fall and Super-Elevation

We consider that cross-fall is a term used to describe the lateral gradient of the road on tangents. Super-elevation is the artificial lateral gradient introduced at curves to improve the ability for vehicles to safely negotiate the corner. A key benefit of lateral gradient in both instances is that it provides the facility for surface water to run off the carriageway surface.

TD9/93 (HA, 1993) indicates that a cross-fall (camber) of 2.5% should usually be maintained to provide adequate surface water drainage.

Elvik *et al.* (2009) highlight that reduced accident rates were found in curves with 'improved' super-elevation. Harwood *et al.* (2000) outline the AMF associated with different levels of 'super-elevation deficiency' (SD) – the difference between the actual super-elevation at a curve and that prescribed in the American Design Guidelines – the AASHTO Green Book. The AMF only applies where the actual super-elevation present is less than that specified by the

AASHTO. Where no local design guidance is available to calculate the super-elevation deficiency the recommended maximum super-elevation is assumed to be 6%.

The AMFs proposed by Harwood *et al.* (2000) are calculated according to three deficiency categories, calculated as below. These imply that a super-elevation deficiency of 2% results in a 6% increase in accident risk, and a super-elevation deficiency of 4% results in a 4% increase in accident risk.

AMF = 1.00	where	$SD \leq 0.01$
AMF = 1.00 + 6(SD - 0.01)	where	$0.01 < SD \leq 0.02$
AMF = 1.06 + 3(SD - 0.02)	where	$0.02 < SD \leq 0.04$

And where:

SD Super-elevation deficiency

TD9/93 (HA, 1993) indicates that super-elevation should not exceed 7% in rural areas. The European research project SAFESTAR (2002) identifies that super-elevation at curves improves safety, but that super-elevation should not exceed 8%. Other than the above, fairly limited direct use of super-elevation in the road safety risk assessment has been identified. Lamm *et al.* (1991) make use of super-elevation to identify the ‘side friction demanded’ for a curve. This factor contributes to the ‘dynamic driving safety’ criterion used by Lamm *et al.* (1995) to complete an assessment of the geometrical consistency of alignments in Germany, Greece, Lebanon and the USA.

3.2.5 Geometric Design Consistency

It is widely recognised that ‘continuity of design’, or ‘relational design’ affects accident risk. Wooldridge *et al.* (2003) in a comprehensive report as part of the NCHRP provide a summary of efforts to define ‘design consistency’, which they propose is typically assessed in one of three ways:

- *Consistency Checklists* formed from subjective assessments or empirically derived measures;
- *Speed Consistency measures* to promote uniform vehicle speeds or reduce speed variability; and
- *Driver Workload Measures* whereby extreme features, unusual features, or a combination of both and their influence on the driver are assessed.

They conclude that geometric design consistency is largely based around driver expectations, and road characteristics that violate these expectations present a road safety risk.

Fitzpatrick *et al*. (2000) conduct a detailed review of alternative design consistency measures for two-lane rural roads. They conclude that the use of driver workload measures to assess consistency has good potential, but that more research is required into defining thresholds indicating limits to driver workload changes. Watters and O'Mahony (2007) echo this conclusion in their literature review and indentify that whilst driver operational requirements has great potential, there is more work required to satisfactorily develop a relationship between driver workload and road safety.

Within speed consistency measures, alignment indices are a general quantitative measure of the consistency of the road, and are usually presented a single ratio for different aspects of alignment, for example:

- The average horizontal radius of curvature for a length of road;
- The ratio of the maximum horizontal radius of curvature to the minimum horizontal radius of curvature for a length of road
- The average tangent length
- The average rate of vertical curvature for a length of road

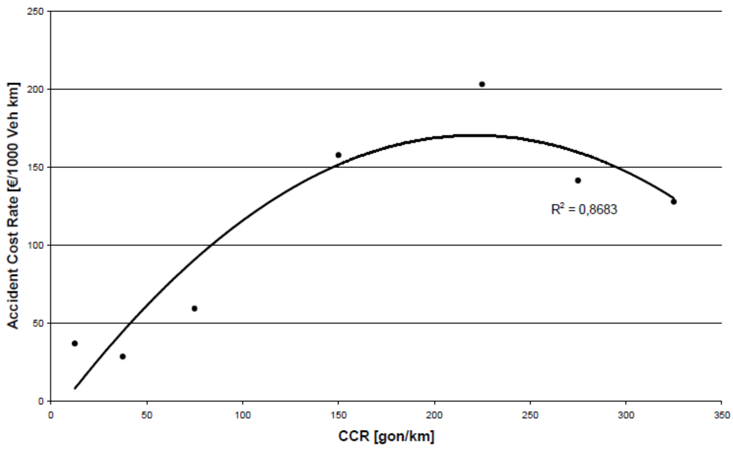
Fitzpatrick *et al*. (2000) conclude that whilst some of these 'alignment indices' demonstrate statistically significant relationships to accident frequency, this relationship is not as strong as that exhibited by a measure which uses speed reduction on sequential elements. They therefore recommend that the Interactive Highways Safety Design Model (IHSDM) use a speed prediction model as the basis for the design consistency module.

More information on the use of operating speeds as a speed consistency measure is provided in Section 3.4, which addresses vehicle speed and vehicle speed operating models. A measure of geometrical design consistency related to speed measures, and widely documented in Europe, is the Curvature Change Rate (CCR). The CCR is the average degree of curvature over a length of road, and usually presented in either degrees per kilometre, or gon per kilometre. It has been shown to be interchangeable with vehicle operating speed as a geometric consistency measure (e.g. a summary in Dietze *et al.,* 2005), and Lamm *et al.* (1995) provide three ranges of CCR which equate to the same 'poor', 'fair' and 'good' design consistency classifications as derived for change in vehicle operating speed (see section 3.4), which are shown in Table 4 below.

Table 4 – Geometrical Design Consistency by CCR (Lamm *et al.,* 1995)

	Geometric Design Consistency Measures		
	Good Design	Fair Design	Poor Design
Curvature Change Rate, *CCR*	*CCR* ≤ 180gon/km	180gon/km < *CCR* ≤ 360gon/km	*CCR* > 360gon/km

Cafiso *et al.* (2007) found that the above classifications were justified by classifying accident data from an International database and performing tests on the difference in accident rates between them. They found that accident rates on roads with CCR in the range [180, 360] gon/km were between two and three times higher than accident rates on roads with CCR < 180gons/km, and that sections of road with CCR > 360gons/km were in excess of eight times greater. Polidori *et al.* (2011) as part of their literature review identify that sections of road with CCR in excess of 100-150 gon/km present an increased risk. Figure below, is re-produced from Hammerschmidt (2006), which describes the effect of CCR on accident cost rate.



Effect of CCR on Accident Cost Rate (Hammerschmidt, 2006)

At first glance this would appear to disagree with the categories proposed previously. However, accident cost rate as a measure implies that both accident frequency and accident severity are taken account of. Therefore we see that the reduced vehicle speeds associated with higher values of CCR likely result in reduced severity, and therefore reduced accident cost rates.

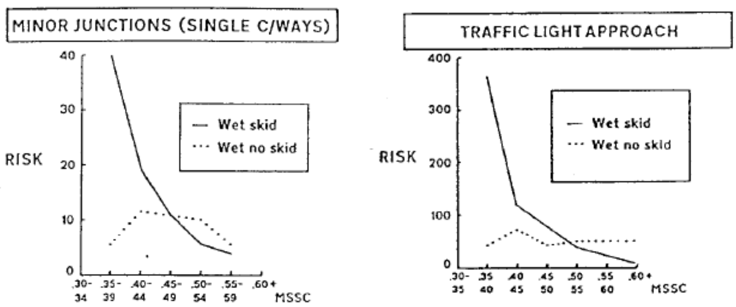
3.3 Road Surface Condition

The ability for drivers to be able to accelerate, decelerate and change direction is dependent on there being sufficient friction available at the contact patches between the vehicle and the road. The friction available is influenced by numerous factors – one of which is the road surface condition. EC (2011) identify that the skid resistance of a road pavement is an important road safety factor, particularly in wet road conditions. The literature identifies furthermore that skid resistance is particularly important in circumstances that demand increased levels of surface friction to perform manoeuvres safely, for example on the approach to a junction, on a negative gradient, at a sharp curve or where the road surface texture depth is low.

Skid resistance is recognised as significant as it is largely undetected by drivers in advance of the hazard. This is in contrast to geometrical or roadside hazards, which providing sight distances are adequate can be seen by the driver who is able to adjust their speed accordingly. Page and Butas (1986) investigated skidding resistance values for California State Highways by geometrical feature. They found that the accident rates on curves were significantly greater than on any other geometrical classification, and that roads with a sideways friction coefficient (SFC) in the range 0.17-0.25 were 23 times higher than those on curves with skidding resistance in the range 0.26-0.54. Further, they noted that when SFC < 0.25, wet accident rates were significantly higher on (both positive and negative) grades greater than 3%.

As part of a study supporting the revision of UK skid resistance standards introduced in 2004, a new assessment of the link between accidents and skidding resistance was made by Viner *et al.* (2005). For single carriageway non-event sites (i.e. those areas away from junctions and with a horizontal radius of curvature greater than 500m), Viner *et al*(2005) found a largely linear relationship between accident risk and skid resistance. Cairney (1997) provides a literature review of the relationship between skid resistance and accident risk. Whilst he states that it is clear that the proportion of wet weather accidents and skidding accidents increases as skid resistance decreases, he notes that the relationship is not always clear, and that many studies are highly specific and not able to be applied generally. For example, he suggests that reports which have found an approximately linear relationship between skid resistance and accident risk often do not include in their sample sites with very low skid resistance.

Viner *et al.* (2005) reference earlier work by Rogers and Gargett (1991) which highlights the relationship they found between skid resistance and accident risk for other scenarios, clearly highlighting the potentially different relationships present according to the site circumstances. This relationship is reproduced in the figure below.



The relationship between accident risk and skid resistance for single carriageways minor junctions and on the approach to traffic lights (Rogers and Gargett, 1991)

HD28/04 (HA, 2004) is the design standard for Skid Resistance on Motorways and All-Purpose Trunk Roads in the UK. 'Investigatory Levels' are used to trigger a further detailed investigation of the site and decision about remedial measures when a site is recorded as having sub-standard skid resistance. HD28/04 (HA, 2004) specifies different 'Investigatory Levels' for different types of site category to take account of the differing levels of friction required. The Investigatory Levels for the ten site categories are presented in Table 5 below. The Investigatory Levels are presented as Characteristic SCRIM Coefficients (CSCs – which take account for seasonality during collection) at 50km/hr.

Table 5 – UK Investigatory Levels by Site Category (HA, 2004)

Site category and definition		Investigatory Level at 50km/h							
		0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65
A	Motorway								
B	Dual carriageway non-event								
C	Single carriageway non-event								
Q	Approaches to and across minor and major junctions, approaches to roundabouts								
K	Approaches to pedestrian crossings and other high risk situations								
R	Roundabout								
G1	Gradient 5-10% longer than 50m								
G2	Gradient >10% longer than 50m								
S1	Bend radius <500m – dual carriageway								
S2	Bend radius <500m – single carriageway								

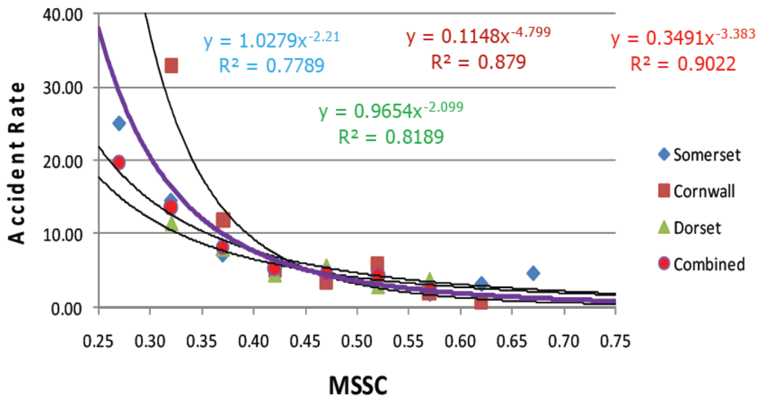
HD28/04 (HA, 2004) notes that these standards have been calibrated based on accident relationships investigated on the UK Motorway and Trunk Road Network and therefore may not be suitable for Local Authority-owned roads – many of which will be rural single carriageways.

Three Local Authorities in the South-West of England, for example, commissioned a study to compare accident rates and skid resistance in order to develop their own, network-specific investigatory Levels (Donbavand and Kennedy, 2008). Whilst Table 5 provides a good general guide to acceptable skid resistance levels according to site category, the study by Donbavand and Kennedy (2008) may be considered more typical for application to EuRSI, as these networks contain a far higher proportion of single carriageway roads with more extreme gradients and smaller curve radii.

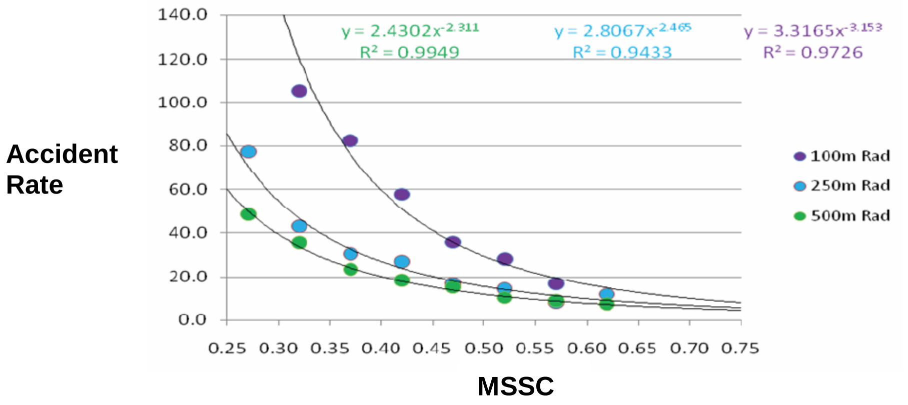
The figure below presents the results of the accident analysis completed by Donbavand and Kennedy (2008) for at least five years accident and maintenance data in South West England. As a result of this study, the authors recommended that the following changes be made to the HD28/04 Investigatory Levels for these road networks:

- That the Investigatory Level for curves with a horizontal radius of curvature, $R \leq 100$m be specified separately (and lower) from those with $R > 100$m;
- That the Investigatory Level for approaches to roundabouts be specified separately (and lower) from the approach to minor/major junctions.

We can interpret these findings directly as, for the same skid resistance, bends with a horizontal radius of curvature, $R \leq 100$m present a greater risk than bends where $R > 100$m, and approaches to roundabouts present greater risk than approaches to minor junctions.



(a)



(b)

The relationship between accident risk and skid resistance (MSSC) for (s) single-carriageway 'non-event' sites and (b) curves with various horizontal radii of curvature < 500m in South-West England (Donabavand and Kennedy, 2008)

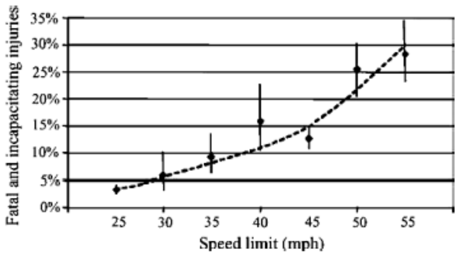
A report by Kokot *et al.* (2009) as part of the TYROSafe European research project identified that at present there are 24 different skid resistance measurement devices in use in Europe and there is no consistent policy relating to the management of skid resistance.

There have been however numerous efforts to try and correlate the measurements of skid resistance from different devices, as evidenced, for example globally by PIARC (Wambold *et al.*,1995) and within the European HERMES research project.

Within the context of this project, we must be cautious that whilst a general understanding of the relationship between skid resistance and accident risk exists, including at sites where skid resistance is particularly important, any benchmark values must be clearly identified as to the measurement method and skid resistance unit used.

3.4 Vehicle Speed

Driving speed is an important factor in road safety. Speed not only affects the severity of a crash, but is also related to the risk of being involved in a crash. Ydenius (2009) reported on work by Garder of a vehicle crash leading to fatal or incapacitating injuries at a given speed limit at the 95% probability based on 3136 vehicle crashes in Maine, USA, during the period 2000–2003. Results, presented in figure, illustrate the rapid rise in serious injury and deaths between 40mph and 50mph.



Fatal of incapacitating injuries compared with increasing speed limits (mph)

3.4.1 The Definition of Vehicle Speed

Various definitions of speed exist in the literature. The following terms have been taken from the American Association of State Highway and Transportation Officials' 'Green Book' (AASHTO, 1994) as well as from National Cooperative Highway Research Programme Report 504 (Fitzpatrick *et al.,* 2003).

- ***Design speed*** is a selected speed used to determine the various geometric features of the roadway. The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use, and the functional classification of the highway;

- ***Operating speed*** is the speed at which drivers are observed operating their vehicles. The 85th percentile of the distribution of observed speeds (V_{85}) is the most frequently used descriptive statistic for the operating speed associated with a particular location or geometric feature;

- ***Posted Speed Limit*** is the maximum (or minimum) speed applicable to a section of highway as established by law and usually signed;

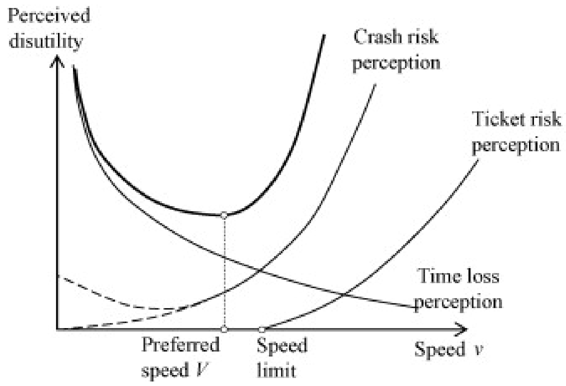
- ***Advisory Speed*** is used at certain locations, such as horizontal curves, intersections, or steep downgrades where the safe speed on the roadway may be less than the posted speed limit. Although the sign provides a warning to approaching drivers, it is not legally enforceable;

- ***Average Running Speed*** is a traffic stream measurement based on the observation of vehicle travel times traversing a section of highway of known length. It is defined as the length of the segment divided by the average running time of vehicles to traverse the segment. ‘Running time’ includes only time that vehicles spend in motion.

Donnell *et al.* (2009) provide a useful review on the definitions of vehicle speed and some of the concepts that surround it. They provide a further distinction between ‘designated design speed’ and ‘inferred design speed’, whereby designated design speed is explicitly determined during the design process (according to design standards). However, designers may exceed minimum values for a given design speed in their geometrical design and therefore the ‘inferred design speed’ (that represented by road on as built) is often greater than the design speed.

Vehicle speed is of significant interest to road users and Road Authorities alike as it influences both mobility i.e. travel time, and safety performance measures of a network. The factors influencing vehicle speed are recognised to include both the characteristics of the road, and the behavioural characteristics of the driver. Aarts and VanSchagen (2006) found that that crash rate increases faster with an increase in speed on minor roads than on major roads. At a more detailed level, lane width, junction density, and traffic flow were found to interact with the speed–crash rate relation. Other studies looked at speed dispersion and found evidence that this is also an important factor in determining crash rate. Larger differences in speed between vehicles are related to a higher crash rate and that without exception, a vehicle that moved faster than other traffic around it, had a higher crash rate.

DeLeur and Sayed (2002) developed a risk index methodology that was based on driver’s subjective assessment of the potential road safety risks for in-service roadways. The objective of this approach was to produce a technique to support road safety analysis that did not rely on deteriorating collision data. The road safety risk index was developed and tested to ensure consistency between observers in their subjective assessment of safety. In addition, the results from the risk index were compared with results from objectively derived road safety measures to evaluate the success of the road safety risk index. The comparison indicates that there is a statistically significant agreement between the results of the risk index and the objectively derived road safety measures. Tarko (2009) detailed results on a study to model three components of speed choice (safety, time, and enforcement) where perceived crash risk and speed enforcement are considered as speed deterrents whilst the perceived value of a time gain is considered as a speed enticement. The study focused on four-lane rural and suburban roads in Indiana, USA. The behaviour of two types of drivers (trucks and cars) was modelled. The density of intersections, land development along the road, and the presence of sidewalks were the identified the prominent risk perception factors. Tarko (2009) reported that a number of investigations of driver speed selection indicated that driver-preferred speeds are affected by the socioeconomic characteristics of the driver, as well as by the road geometry, speed limit, and weather conditions.



Speed deterrent and enticement in speed selection (after Tarko 2009)

3.4.2 Vehicle Speed and Accident Risk

From a safety perspective, speed is widely understood to influence *both* accident likelihood and accident severity. Accident likelihood increases, for example, as the driver has less time to react to a dangerous situation and the braking distance of the vehicle is increased. Increased vehicle speed to known to relate to accident severity for reported accidents as, for example, the Impact speed with other, vulnerable road users, is increased; and the impact speed of the vehicle with any roadside feature is increased, meaning that more energy is required to be absorbed by the driver or passengers.

In research acknowledged by the European Commission (EC, 2011) to be representative and actively used by Scandinavian, Dutch and Australian road safety engineers, Nilsson (2004) investigated a power model to relate speed to accident risk and established that the likelihood of being involved in an injury accident increases approximately with the square of vehicle speed. Further, the probability of sustaining serious and fatal injuries increases with speed to the power of three, and speed to the power of four respectively.

In a comprehensive study completed in the United Kingdom on rural single carriageway roads, Taylor *et al.* (2002) conclude that accident frequency increased with speed to the power of approximately 2.5. Further, the relationship of speed to accident risk was found to vary with other characteristics of the road, including:

- Accident frequency was greatest on sections of road with high hilliness, bend density and low traffic speeds.
- Each additional ‘sharp bend’ per kilometre (those with a chevron and/or bend warning sign) increased accidents by 13%;
- Each additional minor junction crossroads per kilometre increased accidents by 33%.
- The effect of mean speed was found to be particularly large (power of about 5) for junction accidents.

Similarly, Aarts and VanSchagen (2006) found that that ‘crash rate’ increases faster with an increase in speed on minor roads than on major roads. Lane width, junction density, and traffic flow were also found to interact with the speed-accident frequency relationship. Other studies looked at speed dispersion and found evidence that this is also an important factor in determining crash rate. Larger differences in speed between vehicles are related to a higher crash rate and that without exception, a vehicle that moved faster than other traffic around it, had a greater likelihood of being involved in an accident.

Donnell *et al.* (2009) continue to suggest that from a (road safety) engineering perspective, ‘*speed discord results when design speed, operating speed, and the posted speed limit are not compatible*’, although they appear to concentrate most on designated design speeds and posted speed limits in determining whether ‘speed discord’ exists on a length of road. McLean (1979) examined the relationship between horizontal curve design and operating speeds on 120 sites in Australia. In criticism of the design speed concept he noted that roadway designs that conform to design speed standards do not ensure a consistent alignment. Secondly, he suggested that ‘free-flow speeds’ (analogous to vehicle operating speeds) and design speed are not necessarily equal and that in particular vehicle operating speeds on sections of roads with design speeds below 100 km/hr tended to continually be in excess of the design speed. Here, in determining the most appropriate measure(s) of speed to use and when, lies much of the interest from EuRSI’s perspective. Although the posted speed limit and its relationship to the operating speed of the vehicles is of interest to the Road Authority, it is not the core focus of this study. We consider that the most pertinent measures of speed are the inferred design speed and the vehicle operating speed. We also consider that the inferred design speed, as represented by the geometrical elements as built on the road, could be used as a benchmark to represent the maximum ‘safe’ speed for that element.

3.4.3 Geometrical Design Consistency using Vehicle Speed

As previously identified, vehicle operating speed consistency is widely accepted as being the most significant means by which to highlight geometrical inconsistency, and therefore risk to road users. Watters & O'Mahoney (2007), in completing a literature review, report that vehicle operating speed, V_{85}, can be used in consistency evaluation in the following two ways:

- By examining the difference between the design speed, V_D and V_{85} on a particular section of highway; and
- By examining the differences between V_{85} on consecutive highway elements, i.e. the change in vehicle operating speed, ΔV_{85}.

Himes *et al.* (2010) identifies that the foundations for assessing geometrical design consistency are contained in research by Leisch & Leisch (1977). McLean (1979) extends the principle of design consistency and states that for any curved element, the different between V_D and V_{85} should not exceed 10km/hr. He also considers the change in estimated vehicle operating speeds from one geometrical element to another, ΔV_{85}, and concludes that a speed reduction of more than 10 km/hr is undesirable, and an estimated speed reduction of more than 15 km/hr between elements is unacceptable.

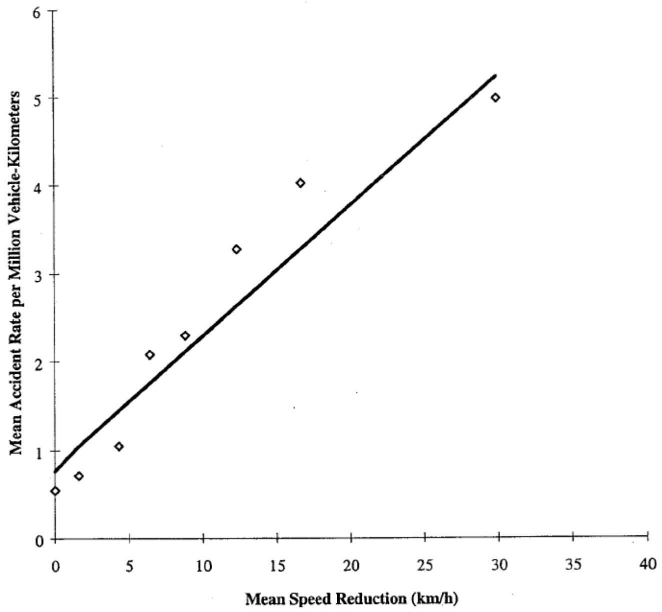
Lamm *et al.* (1988) provided a review of European design guidelines to suggest some objective criteria to qualify the design consistency of a length of road. They used previously developed accident prediction models in New York State to categorise curves according to the change in the degree of curvature, ΔDC, and mean accident rates. From these, and equating ΔDC *to* ΔV_{85} through an estimated speed model, he proposed 'good', 'fair', and 'poor' design principles associated with ΔV_{85}. Further, the same classification for the difference between the design speed, V_D and V_{85} on a particular section of highway was also proposed, the results of which are presented in Table 6 below.

Table 6 – Geometrical Design Consistency Classes (Lamm *et al.,* 1988)

	Geometric Design Consistency Measures		
	Poor Design	Fair Design	Good Design
Reduction in vehicle operating speed between adjacent elements	$\Delta V_{85} \leq$ 10km/hr	10km/hr < $\Delta V_{85} \leq$ 20km/hr	ΔV_{85} > 20km/hr
Difference between Vehicle Operating Speed and Design Speed	$V_{85} - V_D \leq$ 10km/hr	10km/hr < $V_{85} - V_D \leq$ 20km/hr	$V_{85} - V_D$ > 20km/hr

These principles and the critical ranges proposed continue to be well used and form the basis of geometric consistency assessments within the IHSDM Design Consistency Module (IHSDM-DCM). In Europe, these same thresholds are used in determining the Safety Index within the European IASP research project (Cafiso *et al*. 2007) and are applied in the Highway Design Analysis (HDA) software developed by Castro *et al.* (2008).

Anderson & Krammes (2000) investigated the use of an operating speed model to determine the reduction in speed required for over 1,000 curved sites on rural two-lane roads in the USA. They conclude that curves with a design speed of less than 100km/hr and that require a driver to decelerate from their desired speed on the preceding tangent have higher accident rates than curves which do not require speed reductions. Further, they identify that the scale of the speed reduction influences the accident risk, and that accident risk increases approximately linearly with speed reduction (as shown in the figure below)



Relationship of Mean Speed Reduction to Accident Risk (Anderson & Krammes, 2000)

3.4.4

3.4.5 Vehicle Operating Speed Models

It is clear that any reliance on speed as a measure of design consistency requires speed data for the road network being assessed. A large number of studies have been completed on road factors that affect vehicle operating speed on curves, including horizontal and vertical radius of curvature, gradient, super-elevation, sight distance, lane width, shoulder width, AADT, time of day and weather.

Himes *et al.* (2010) investigate a simultaneous modelling approach to predict V_{85}, and conclude that posted speed limit should not be ignored as an explanatory variable in operating speed prediction models on two-lane highways. They do however note that the posted speed limit did not appear to be correlated with the geometric features of the road, but instead appeared to be related to variables associated with the hierarchical function of the road and surrounding area. The vast majority of models developed however, (and all of the single variable models reviewed) confirm that the most significant factor that influences vehicle operating speed is the horizontal radius of curvature. Generally, it has been found that operating speed decreases as the radius of curvature (or equivalently the degree of curvature) decreases. The most comprehensive review of vehicle operating speed models was completed for North American roads by Fitzpatrick *et al.* (2000a), who provided seven equations as examples used to estimate the operating speed of vehicles on horizontal curves. Of these models, five of the seven used only horizontal radius of curvature, *R*, to explain the variation in V_{85}, and all seven included 1/R as a factor in the model. Fitzpatrick *et al.* (2000a) continued to develop the equations shown in Table 7 which form the operating speed model within the IHSDM-DCM. These are stated as being the first set of equations that address operating speed models considering both horizontal and vertical curvature.

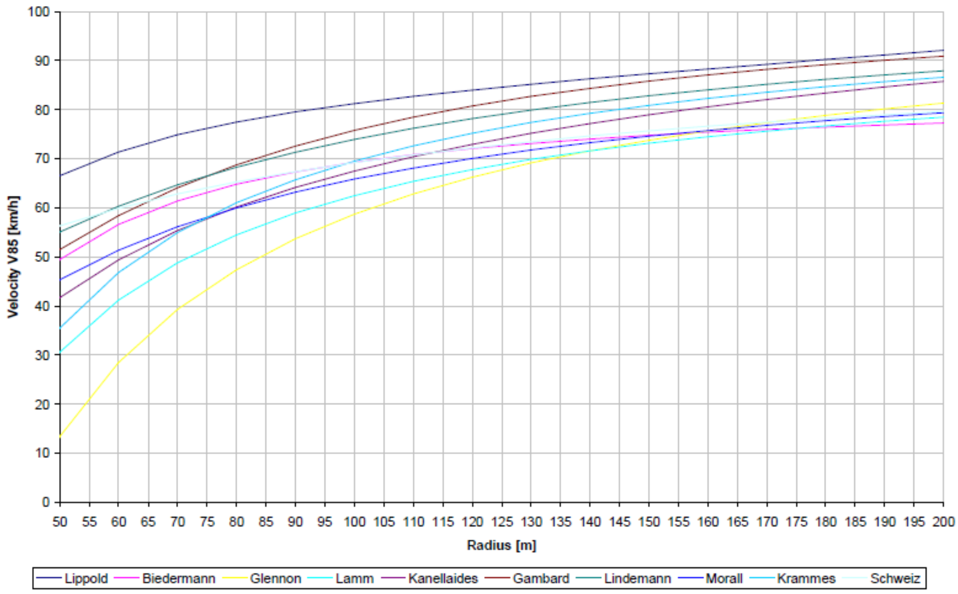
Table 7 – IHSDM Operating Speed Models (Fitzpatrick *et al.,* 2000a)

	Geometric Feature	Alignment Condition	Operating Speed [km/hr]
1	Horizontal Curve	-9 % ≤ G < -4 %	V_{85} = 102.10 – (3077.13/*R*)
2	Horizontal Curve	-4 % ≤ G < 0 %	V_{85} = 105.98 – (3709.90/*R*)
3	Horizontal Curve	0 % ≤ G < 4 %	V_{85} = 104.82 – (3574.51/*R*)
4	Horizontal Curve	4 % ≤ G < 9 %	V_{85} = 96.61 – (2752.19/*R*)
5	Horizontal Curve	Sag Vertical Curve	V_{85} = 105.32 – (3438.19/*R*)
6	Horizontal Curve	Non-limited Sight Distance Crest Vertical Curve	Use lowest speed of the speeds predicted from equations 1 or 2 (for the downgrade) and 3 or 4 (for the upgrade)
7	Horizontal Curve	Limited Sight Distance Crest Vertical Curve (*K*<43)	V_{85} = 103.24 – (3576.51/*R*)
8	Horizontal Tangent	Sag Vertical Curve	V_{85} = Assumed Desired Speed
9	Horizontal Tangent	Vertical Crest Curve with Non-Limited Sight-Distance (*K*>43)	V_{85} = Assumed Desired Speed
10	Horizontal Tangent	Vertical Crest Curve with Limited Sight-Distance (*K*>43)	V_{85} = 105.08 – (149.69/*K*)

Castro *et al.* (2010) highlight that whilst these are the best known and most widely applied speed operating models due to the size of the sample size and the practicality in their application, it remains that the model has been calibrated and validated using data from rural two-lane roads in the USA. Subsequently, there have been several papers published that seek to address the suitability of the above models to other environments, and particular reference is made to the reliance of the models on the 'assumed desired operating speed' chosen by the user of the IHSDM. For example, see the studies by Senica and Milosevic (2006) in Serbia, Castro *et al.* (2008) in Colombia and Chai *et al.* (2009) in the UK.

All papers conclude that the country-specific models – even those using a single explanatory variable - provide more accurate results, particularly at small and large horizontal radii. This would appear though to some extent though to be expected: In the examples reviewed the country-specific models are calibrated using the data collected and not subject to other data for validation – for example elsewhere in the country. We would therefore expect these models to explain the operating speed more accurately than the IHSDM model. The country-specific nature of these findings however is supported further by findings within the European SAFESTAR research project (SAFESTAR, 2002). Here, operating speed models for Greece, Finland, France and Portugal were developed, but a general model, independent of nation, could not be fitted satisfactorily.

Lamm *et al.* (1995) use various regression models for the United States, Germany, Greece and Lebanon to calculate recommended consistency characteristics according to the evaluation criteria from Lamm *et al.* (1988) – shown in Table 6. In respect of transition elements, i.e. a curve following an independent tangent (one where the speed is not dependent on the preceding curve) the minimum radius curve that could be classified as "good" relational design is 500m in Germany, and 400m in Greece. The difference in these values can be attributed to the fact that the operating speed models employed differ from Greece to Germany (specifically that faster vehicle speeds across all curvature change rates were observed in Germany). An example of differences in country-specific models is provided in the literature review of the PILOT4SAFETY European research project (Polidori *et al.,* 2011), and is re-produced below in the figure below.



Relationship of Horizontal Curve Radius to Estimated Vehicle Operating Speed for Different Vehicle Operating Speed Models (Polidori *et al.,* 2011)

A general note of caution raised by much of the literature is the ability of largely linear models (for both tangents and curves) to accurately estimate operating speeds on long straights, or on very low radius curves. Bird and Hashim (2005), for example, highlight that in their model for operating speed on tangents, the independent variable 'tangent length' may result in unrealistically large operating speeds for very long tangents. The IHSDM-DCM overcomes this by limiting speeds on tangents to the 'assumed desired speed' – usually 100km/hr.

Equally, within their development of a GIS tool to evaluate road safety in Spain, Castro *et al.* (2008) note that many of the operating speed models that exist provide an unrealistically small value for ΔV_{85} on curves with small radii and therefore introduce a minimum speed bound into their prediction model. Further, within their HDA software developed, they include the following general equation to predict vehicle operating speed – the parameters of which can be customised according to locality:

$$V_{85} = a + b.\frac{1}{R} + c.L + d.\Omega$$

Where

R Horizontal radius of curvature [m]

L Length of horizontal curve [m]

Ω Angle of deflection [deg]

3.5 Role of Historic Accident Databases

Historical data on road accidents contains a lot of valuable information about accidents that have occurred along a particular stretch of road or road network. It tells us where and when the accident happened, how many people and vehicles were involved and the severity of the accidents in terms of injuries or fatalities. It also stores some information about the car, environmental factors, such as weather and light conditions or nearby road works, as well as details about the driver's background, such as age, sex and familiarity with the location.

All these descriptors are very helpful to get a broader picture about the nature of an accident. However thus same detail also demonstrates the complexity one faces when dealing with road safety. Accidents can result from a number of contributory factors. We can, typically, separate these into the following four groups; static road factors, dynamic environment conditions along the road, the vehicle and the driver. Dynamic environment includes; weather and light conditions, seasonal influences or wild animals crossing the road. In this project we decided to focus exclusively on static road factors. That means we look at a variety of different physical road features that do not change or change very slowly over time. These features include horizontal and vertical alignment, road width, skid resistance, super-elevation, static hazards and surface condition. Clearly there are many different reasonable ways for performing such an assessment. For instance one could choose a statistical approach which naturally would rely heavily on a given accident database. Another approach could be based on general engineering principles. In this approach, an accident databases will play a lesser role and will mainly be used to judge to what extent the obtained risk weightings reflect reality. We will argue that despite the insight that can be gained from a database, it has many inherent flaws which cannot be resolved easily and thus may render a statistical approach less robust.

One of the chief challenges with an accidents database is the lack of understanding in terms of factors themselves and their intrinsic contribution to any given accident. Driver’s action or reaction to various scenarios can vary widely. Such variations are not incorporated in a database and so a purely statistical model will not be able to distinguish any two cases. For instance consider accidents that occur due to inappropriate, irresponsible, reckless behavior along a section of a road which from an engineering perspective is to be considered safe. Such a data point in our database might suggest there is something wrong with the set of road factors at this road segment whereas in reality the driver was the problem. On the other hand a very dangerous part of a road might lack a history of any major accidents whereas a similar set of physical road features may cause frequent accidents somewhere else. This might be due to some other condition being present in the first scenario which subconsciously triggers the driver to take more care whilst no such reaction is sparked in the second scenario. But if we have no data for such an undetected condition our statistical model will not be able to distinguish between both cases and will find them less dangerous than they actually are. Overall that means there is an uncontrollable amount of noise in the data due to human behavior and attitude. Consequently a statistical model will be influenced by this noise, potentially leading to an undesired misinterpretation of the input data that may result in labeling relatively safe roads as less safe and relatively dangerous roads as less dangerous.

We can argue similarly with other potentially decisive factors like weather and light conditions, seasonal influences and other unusual occurrences which have nothing to do with the actual road or the static road environment. It is hard to predict to what degree such factors influence road safety in general, it is almost impossible to say how much they contributed to any given accident in the database. That means we have every reason to doubt whether it is reasonable to attribute the same significance to every accident in the databases. Consider for instance a road segment A for which we have a record of six accidents and a road segment B with a total of three accidents. If we treat each accident alike then the road A appears more dangerous than road B and consequently a statistical model will assign a higher risk to the set of road features associate to road A. But now suppose that all accidents on road segment A are accompanied by high traffic and unfavorable weather and light conditions, whereas road segment B is very calm and the accidents happened under good conditions. Would this additional information not alter our risk assessment of the roads A and B and is it fair to apply a statistical technique which cannot distinguish between any of the outer conditions? At the same time just because some external condition is present this still does not necessarily mean that the physical road is free from all blame.

All this implies that a statistical analysis of road factors will inevitably rely on data where an unknown proportion is inappropriate for this use as road factor may have little or no contribution to the accident. This deficiency in that data is hard to resolve and cannot be solved using the database alone. Of course one could argue that once we acknowledge that dynamical features like weather condition contribute to accidents we just have to incorporate them in our statistical analysis to avoid a skewed result. Unlike driver's behavior there is data, if only limited, on other factors available. But the more features we consider the more complex and the less reliable the model will become in general. Furthermore we will still have to deal with the uncertainty of how much a feature contributed in the first place.

Another shortcoming with using an accident database is the quality of the data. Often the number of data points is very scarce. Usually a road section reports a low number of accidents. Given the variety of road factors we are interested in and considering other factors that influence the data, a small number of data points makes it rather unlikely to deliver a realistically result. Furthermore since we are looking at historical data, the road conditions themselves may have changed over the years. That means considering two accidents from two separate occasions say two years apart on the same road segment does not guarantee the exact same road network factors. Other relevant information like traffic conditions at the time of the accident or the actual driving speed are often missing from the data leaving gaps which need to be computed using average values. There are many different people contributing to the database using their own assessment and judgment of the situation causing inconsistencies in the data. Also, most database attributes are recorded categorically, for example, dry or wet weather conditions. This leads to a lack of variability and an unjustified averaging from the start. One final issue with an accident database is not the database itself but the means by which we analyse it. There are a large variety of different models that can be employed in any analysis, many leading to different results. Which statistical model should be used and how can we assess the quality of the model and tune its parameters? Another problematic area is the high level of uncertainty in our assessment since any such prediction and validation process will based around the same database used to construct the model.

All these points underline the difficulty of a purely statistical approach which relies heavily on an accident database that may be based on a small sample size, inconsistent and incomplete, and thus can lead to an undesired averaging and distortion of the result. However, accident database can help the road safety engineer prioritise safety improvements by simply highlighting locations where collisions occur or be revealing a section of road that requires further or more detailed investigation though a pattern of spatially connected accidents. Accident database should always be employed in the risk screening process in conjunction with an RSI.

3.6 Discussion

Risk can be influenced not just by static and dynamic road network factors but also the status of the vehicle as well as more complex driver behaviour. The context of this investigation into risk assessment is RSI along rural road so, general scope is limited to the static factors associated these road networks. We don't consider the transient effects of weather, illumination or the possibility of wild deer crossing the road. This Chapter described some of the main static risk factors in terms of the physical static road environment. These are road network factors that are at the very heart of road safety inspection and typically change very slowly with time such as, geometry elements, surface condition and hazards. Each factor's relative input to overall risk can be understood in robust, well documented engineering terms when the factor is considered on its own and for a specific driving profile type e.g. a horizontal curve of 350m has a top velocity limit of 48km/hr, all other inputs being equal. There are a number of questions here in the context of risk assessment associated with an RSI;

- Under what broad assumptions are we defining risk for example, do we assume the driver is always driving at a particular speed
- How can various factors contribution to risk be computed when they occur at one location
- How can risk be universally computed in terms of multiple causative factors across multiple rural road network types?

Road user safety risk is usually computed from likelihood, severity as well as exposure. Risk can be visible e.g. a bad road bend after a straight section or hidden e.g. poor SCRIM or rock outcrop behind grassy vegetation. Several risk prediction models have been examined in the course of this study and can, with a few exceptions, be broadly classified into global as well as scenario, local based approaches. The role of historic databases in these models as well as the shortcomings has been described. Overall, these approaches fall short of what is required for risk assessment associated with RSI where robust, scale-dependent, timely, transparent information is required under operational conditions. A more pragmatic solution is required that can integrate mobile mapping technology to record the tangible static road environment as well as other related data sources to compute the less tangible risk component.

One of the main findings of this study is the need to establish a linkage between the static physical road network environment and the concept of a 'safe profile' velocity. This safe profile velocity, V_{SP}, is recorded using onboard GPS under typical (daylight, fair weather, free-flow) conditions, ideally, at the same time as the mobile mapping system data-acquisition. The driver is instructed to drive so as to ensure a safe, comfortable profile over the entire survey section. V_{SP} can be used as a proxy for perceived risk of the static road factors, as measured by the mobile mapping system. A framework is required to integrate both these quantities, in order, not just to highlight risk but also explain in a more meaningful way the inherent risk value at any particular location. This framework should be based on robust engineering principles, offering rapid discovery of risk along the route as well offering the user clear evidence as to why a particular location has a risk rating. This framework should be straightforward to implement and use under operational conditions.

3.7 Conclusions

A number of static road factors were examined and described in terms of their structure, characteristics and contribution to risk in the context of RSI along rural roads. The table below details some of the elementary rules, extracted from preceding sections, that could be used for highlighting potential risk along rural roads

Factor	Threshold Rule
Horizontal Alignment	curves, R < 400m
	curves R <100m
	180gon/km < CCR ≤ 360gon/km
Vertical Alignment	grades <6%
	crests more dangerous than sags
Cross-section	lane width < 3.5m
	existence of a hard-shoulder < 1.3m
	cross-fall >= 2.5%
	super-elevation < 7%
Surface Condition	SFC < 0.25

Table 8. Elementary rule base for highlighting sections of road that present risk

The role of vehicle speed and its contribution to overall risk was explored. Accident databases have been used in countless risk assessment studies but possess a number of significant shortcomings. The datasource is valuable but care needs to be exercised when incoporating any data into risk models and interpreting the results. The role of velocity can not be under-estimated and perhaps one of the main findings in this study is identifying the need to link velocity eg safe profile velocity, $V_{SP,}$ with static road factors, as mapped by mobile mapping system, in order to highlight and understand risk components within the context of RSI.

4 A proposed framework for assessing risk within the context of road safety inspection along rural roads

4.1 Introduction

Road safety management is an important means for forecasting and preventing traffic accidents. At its core is measurement, analysis of various factors as well as the ability to understand, predict outcomes in order to take positive action in maximizing road safety. The three main road safety risk domains or sources of risk for road users can be attributed to the driver, the vehicle and the road environment. The latter includes static road geometric elements such as various aligment & cross sectional attributes as well as transient phenomemna such as traffic flow, illumination, weather etc. Understanding the various dynamic interactions of driver, vehicle and road environment is key to designing & implementing a comprehensive and sustainable road safety programme.

As stated in the first chapter, the overall objective of this work-package is to formulate a road safety risk assessment methodology to highlight locations and sections along rural road network that require safety interventions based on information acquired during RSI and any other relevant, information. This risk assessment methodology will be used by the algorithms development group, in an associated work-package, to construct risk assessment software modules. These modules will need to be tested and validated so, the proposed methodologies below are not meant to be prescriptive or definitive but rather provide a general framework to guide implementation. Various RSI related safety assessment issues have already been identified in first chapter and give rise to a number of fundamental challenges in determining a suitable approach to risk assessment, these include;

- Designing a suitable, transparent methodology to describing risk and highlighting high-risk locations
- Determining the form of the output from any road safety risk assessment and ensuring this is readily interpreted by the Road Authority
- Deciding what level of information in terms of detail and quality we want to achieve;
- The selection and collation of suitable road safety factors relating to road geometry, surface condition and road side features
- Investigating the role of speed, specifically V_{SP}, in computing risk
- Devising a framework that brings together static road factors, V_{SP}, accident database to provide a robust, timely, evidence-based RSI risk assessment information system

We begin by defining and describing various terms such as road safety risk, factors, exposure. Road safety risk is understood in the context of this project to be a combined measure of the likelihood of having an accident and severity of adverse effects following a collision;

- Accident Likelihood: The probability that an accident will occur;
- Accident Severity: The severity of personal injuries sustained by road users in the event of an accident;

Allied to Road Safety Risk is the concept of exposure. This provides some understanding of how road safety risk may be reflected in the number of accidents observed and helps us understand the exposure of road users to road safety risk. This element is particularly important to the responsible Road Authority, who is likely to use exposure as a basis for economic justification of road safety engineering interventions. A number of exposure indicators have been examined within the SafetyNet (2008) project, these include;

- Vehicle kilometres
- Person kilometres
- Vehicle fleet
- Driver population
- Road length
- Population
- Number of trips
- Time in traffic
- Fuel consumption

Average Annual Daily Traffic (AADT) can be used to describe the exposure to accident risk.

This project proposes a framework comprising three levels of processing to detect and highlight risk along rural road networks. The first part of this chapter deals with the road factors that should be measured. The final section in this chapter details a novel framework for bringing these factors together enabling rapid detection and assessment of risk.

4.2 Road Safety Risk Factors

In order to quantify the risk to road users, we need to define road safety risk factors – or more specifically a 'factor' that influences the road safety risk. Based on the components of risk already defined, we are able to classify any factor as an accident likelihood factor, an accident severity factor or a global factor i.e. both an accident likelihood factor and an accident severity factor. These have been discussed in more detail later in the preceding chapter and in the context of this study will be limited to

- Road geometry
- Surface Condition
- Road Side features

Table 9 details the factors proposed to form part of the EuRSI Road Safety Risk Assessment, drawn from RSI data. These factors have been proposed with due consideration of the limited complexity sought and a desire to accommodate as much automatic data capture and processing as possible. The risk factors are classified according to the RSI data type and are identified either as an accident likelihood factor, an accident severity factor, or both an accident likelihood factor and an accident severity factor.

EuRSI Road Safety Risk Factor		**Nomenclature**	**Units**	**Capture/ Processing**	**Road Safety Risk Factor Class**	
Ref.	Name				Likelihood	Severity
RSI Data Type 1 – Horizontal Alignment						
1.1	Horizontal Radius of Curvature	R_H	m	Auto	✓	
1.2	Curvature Change Rate*	*CCR*	$gon.km^{-1}$	Auto	✓	
RSI Data Type 2 –Vertical Alignment						
2.1	Vertical Radius of Curvature	R_V	m	Auto	✓	
2.2	Vertical Gradient	*G*	-	Auto	✓	
RSI Data Type 3 –Cross Section						
3.1	Number of Lanes	N_L	-	Semi-Auto	✓	
3.2	Lane Width	W_L	m	Semi-Auto	✓	
3.3	Recovery Zone Width	W_{RZ}	m	Semi-Auto	✓	
3.4	Cross-fall	*C*	-	Auto	✓	
3.5	Super-Elevation	*SE*	-	Auto	✓	
RSI Data Type 4 –Road Skid Resistance						
4.1	SCRIM Coefficient	*SCRIM*	-	Auto	✓	
RSI Data Type 5 –Roadside Hazards						
5.1	Distance of Point Hazard from Road Edge	D_{PH}	m	Semi-Auto		✓
5.2	Type of Point Hazard	HP_{CLASS}	-	Semi-Auto		✓
5.3	Distance of Linear	D_{LH}	m	Semi-Auto		✓

	Hazard from Road Edge					
5.4	Type of Linear Hazard	HL_{CLASS}	-	Semi-Auto		✓
RSI Data Type 6 –Junction/Crossing Hazards						
6.1	Type of Junction	J_{TYPE}	-	Semi-Auto	✓	✓
6.2	Junction Channelisation Facilities	J_C	-	Semi-Auto	✓	
RSI Data Type 7 –Other Data						
7.1	Presence/Visibility of Road Markings at Hazard	RM	-	Semi-Auto	✓	
7.2	Presence/Visibility of Traffic Signs at Hazard	TS	-	Semi-Auto	✓	
7.3	Safe Profile Velocity*	V_{SP}	km.hr^{-1}	Auto	✓	✓

* These factors are not directly collected from the RSI, but instead calculated from other geometric variables

Table 9. Road geometry, surface condition and road-side features

Most of the intrinsic road geometry factors and surface condition are self-explanatory in the above table. Some other factors are not so clear in how they will be recorded, and these are now described in more detail.

4.2.1 Point Hazards

Point hazards (Table 10) should be considered as any isolated natural or artificial obstacles whose inside edge is located less than 10m from the edge of the road and that lies in between the edge of the road and a linear hazard that bounds the road. Point hazards which are evident within other *linear* hazards (e.g. a post within a ditch, or a particular out-crop on a length of rock face) should be identified as separate point hazards in the risk assessment. Where a 'recovery zone' (i.e. a hard strip) exists, the 'Distance of Point Hazard from Road Edge', D_{PH}, should be measured from the edge of carriageway marking – i.e. it includes this hard strip. Where no hard strip exists, D_{PH} should be measured from the edge of the paved surface or from the kerb face. Although EuRSI is focussed on single carriageway roads, there are often short lengths of road which may be dualled to provide safe overtaking opportunities. We therefore consider that roadside point hazards may form either nearside point hazards or median point hazards.

Type of Point Hazard		**Assumed Typ. Diameter**	**Comments**
Ref.	Name	[m]	
PH.1	Small Tree	>=0.1	
PH.2	Large Tree	>=0.5	

PH.3	Utility Pole	0.25	
PH.4	Lighting Column	0.19	
PH.5	Masonry/Concrete/ Steel Structures	-	Bridge Abutments, gantry supports, pylons
PH.6	Cabinet/Housing	-	Usually metal-built housing for electrical/ telecommunications equipment
PH.7	Traffic Sign Post	>=0.09	'Passively Safe' posts or smaller diameter traffic sign posts should not be included as hazards
PH.8	Damaged Guardrail	-	Identify where guardrail (i.e. a vehicle restraint system) has either a gap, or where the terminal is damaged, buried, or incorrectly angled;

Table 10. Roadside Point Hazards

The Type of Point Hazard, $PH_{CLASS,}$ is intended to account for the varying risk that different types of point hazard present through their diameter and construction material.

4.2.2 Linear Hazards

Linear hazards should be considered as any natural or artificial obstacles whose inside edge is located 10m from the edge of the road (perpendicularly to the direction of travel) and that extend for a distance of 25m or more. Any feature that bounds the road and is within 10m of the edge of the road should be recorded as a linear hazard. As with point hazards, we consider that roadside linear hazards may form either nearside linear hazards or median linear hazards. EuRSI's primary focus is on road safety from a car occupant's perspective. Although guardrails (vehicle restraint systems) present a hazard in their own right, we do not consider a properly specified road restraint system as a significant hazard. Only in the case where the road restraint system is damaged or not properly installed, do we consider it either a point hazard (see PH.8 in Table 10) or a linear hazard (see LH.9 in Table 11) and record it as such.

Type of Linear Hazard		**Comments**
Ref.	Name	
LH.1	Ditch	A ditch is considered any depressed channel approximately 0.75m or greater deep at the road edge
LH.2	Earth Cutting	
LH.3	Rock Cutting	
LH.4	Tree Line	
LH.5	Earth Embankment	
LH.6	Masonry/Concrete Wall	Including retaining walls
LH.7	Fencing	
LH.8	Hedging/Shrubs	
LH.9	Inappropriate	Where it is protecting a hazard. identify where guardrail is

	Guardrail	inappropriate for use as a vehicle restraint system (e.g. pedestrian guardrail in place as a bridge parapet)

Table 11. Roadside Linear Hazards

The Type of Linear Hazard, $LH_{CLASS,}$ is intended to account for the varying risk that different types of linear hazard present, largely determined by the material it is constructed from. We assume that the angle that a linear hazard presents to errant vehicles that leave the road is near consistent and approximately parallel to the road edge. Where part of a linear hazard presents a dangerous angle to errant vehicles it should be recorded as a point hazard under one of the categories in Table 10, most likely PH.5.

4.2.3 Type of Junction and Junction Channelisation Facilities

Junctions represent opportunities for joining traffic to come into conflict with traffic on the main route and are recognised as presenting increased risk to vehicle occupants. Junction approaches are also important as it is here where drivers may encounter slowing traffic waiting to turn across traffic, or manoeuvre and brake abruptly to avoid vehicles at the junction ahead.

The different junction types to be recorded as part of the RSI are detailed in Table 12. These different junction types represent the different levels of risk associated with different junction types

Ref.	**Name**
$J_{TYPE}.1$	Roundabout
$J_{TYPE}.2$	Three-Arm Priority Junction
$J_{TYPE}.3$	Three-Arm Signal Controlled Junction
$J_{TYPE}.4$	Staggered Priority Junction
$J_{TYPE}.5$	Four-arm (or more) Priority Junction
$J_{TYPE}.6$	Staggered or Four-arm (or more) Signal Controlled Junction

Table 12 Categorical Factors for Junction Type

In addition to the type of junction, it is also widely recognised that the addition of channelisation at a junction can reduce risk to road users by more effectively segregating traffic flows and reducing conflict areas and providing more information about priorities to drivers.

Junction channelisation facilities, J_C, should be noted wherever a junction is identified to exist. Table 13 provides a list of categories for which Junction channelisation is proposed to be recorded.

Ref.	**Name**

J_C.1	No channelisation facilities provided for turning movements across traffic
J_C.2	Non-physical channelisation facilities (i.e. through road markings) provided for turning movements across traffic
J_C.3	Physical channelisation facilities provided for turning movements across traffic

Table 13 Categorical Factors for Junction Channelisation Facilities

4.2.4 Presence/Visibility of Road Markings and Traffic Signs at Hazard

For all point hazards, linear hazards and junction hazards identified an assessment of the road markings and traffic warning signs should be made. In the case of linear hazards, one assessment should be made per length of homogenous Linear Hazard, $LH_{CLASS.}$. The condition or presence of road markings or traffic signs is proposed to be assessed using the categories detailed in Tables 14 and 15 below.

Ref.	Name
RM.1	Road Markings associated with Hazard Present and Visible
RM.2	Road Markings associated with Hazard poorly maintained or not easily visible
RM.3	Road Markings associated with Hazard not present

Table 14 Categorical Factor for Presence/Visibility of Road Markings at Hazard

Ref.	Name
TS.1	Traffic Sign(s) associated with Hazard Present and Visible
TS.2	Traffic Sign(s) associated with Hazard poorly maintained or not easily visible
TS.3	Traffic Sign(s) associated with Hazard not present

Table 15 Categorical Factor for Presence/Visibility of Traffic Signs at Hazard

4.3 Framework for RSI Risk Assessment

The proposed framework for risk modelling in this study is based on three processes, detailed in Table 16 below. The level of complexity increases for computing risk from relatively simple Level 1 through to Level 3. Meanwhile risk information increases in value moving from left to right. Level 1 involves processing the most recent accident database version to highlight any existing or relatively recent black-spots. This process should also highlight any emerging and un-usual accident clusters that may point to physical road factors. The second process, Level 2, integrates the measured static road factors and V_{SP} within a common reference frame.

Unusual V_{SP} values highlight locations along the road network where particular attention is required. The third process, Level 3, is carried out independently where the databases of static road factors is processed against a series of rules and any positive results are used to highlight locations that require further attention.

Level 1 is used to highlight locations where un-usually high numbers of accidents or peculiar patterns of collisions are found. Level 2 uses thresholded V_{SP} values as a proxy for perceived risk to highlight locations along the road that require further inspection. Level 3 is a detailed processing of the static road factor values independent of V_{SP} values. This is carried out to detect any hidden risk factors e.g. surface condition or indeed factors that are visible but do not trigger any response or change in driver behaviour.

Risk Computation

Process	**Data Inputs**	**Risk Assessment Outputs**
Level-3	Static road factors	Risk highlighted according to rulebase
Level-2	V_{SP} and static road factors	Perceived risk highlighted by V_{SP} and explained by road factors
Level-1	Accident Database	Black-spot Screening, anomalous patterns

Risk Information

Table 16. Conceptual model for risk modelling associated with RSI along rural roads

The proposed procedure is for static road environment factors and V_{SP} to be captured at the same time using the same mobile mapping system. Various qualitative and quantitative values are extracted from the raw data and a table similar to Table 17 below, is constructed. This enables Accident (Acc), Physical Road Elements, Hazards and Velocity to be acquired, measured, classified & integrated at a suitable level of granularity (S) e.g. 1m for each carriageway direction. This table is the basis from which either higher level values can be computed and/or rules applied.

S	Acc	Physical Road Elements											Hazards				Velocity
#	Ac	RH	CCR	R_V	G	NL	W_L	W_{RZ}	C	SE	$SCRIM$	J_{TY}	D_{PH}	HP_C	D_{LH}	HLC	V_{SP}
1	0	600	0.6	0.7	0	1	3.5	0	0	0	0.7	0	0	0	0	0	0.6
2	0	600	0.6	0.7	0	1	3.5	0	0	0	0.7	0	0	0	0	0	0.4
3	0	600	0.5	0.7	0	1	3.5	0	0	0	0.7	0	1	2	0	0	0.4

4	0	400	0.5	0.7	0	1	3.5	0	0	0	0.7	0	0	0	0	0	0.4
5	2	400	0.5	0.7	0	1	3.5	0	0	0	0.7	0	0	0	0	0	0.4
"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n

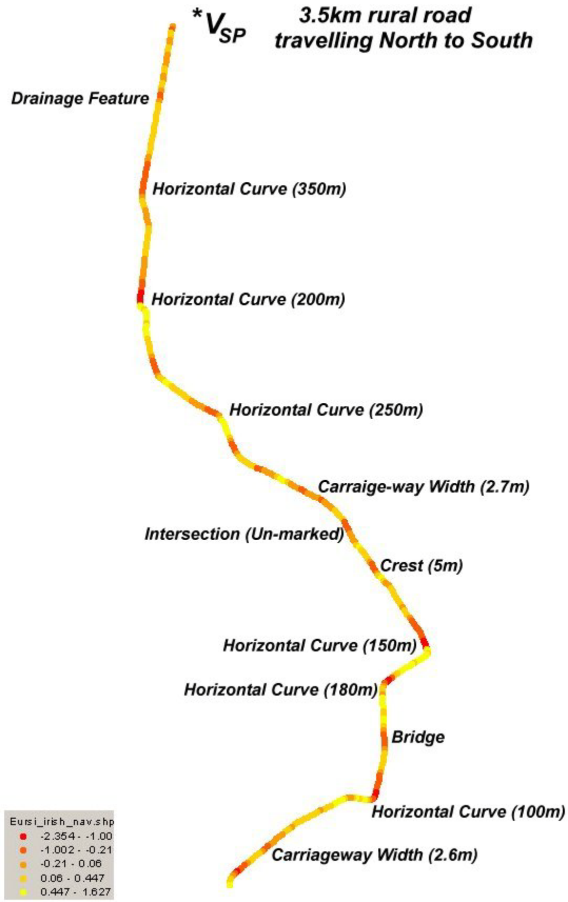
Table 17. Sample values for various Accidents (ACC), Physical Road Elements, Hazards and Velocity

Level-1

Accidents based on location, date, type, & severity are extracted from the original database and filtered against a set of spatial and temporal rules. Results are referenced to road centre line and transposed into main working table for that road network section under appraisal. Any anomalies in terms of clusters or unusual patterns are highlighted in the main table. Ranking will be based on the cumulative values of incident numbers, severity and spatial-temporal values.

Level-2

V_{SP} is the ideal safe profile velocity and used to calculate a velocity and acceleration term that can be used to highlight locations that require closer inspection. It is generally assumed that a road which is perceived as safe is one where V_{SP} is constant relatively high value but below posted speed limit with zero acceleration. Any change in V_{SP} is assumed to be due to some change in the physical road environment e.g. a bend in the road. Transient factors such as effects of weather, poor illumination, sun glare or *one-off* events like braking to avoid collision can be detected in the mobile mapping system and either removed or that section can be flagged to be re-surveyed. If we take the example of a car negotiates a transition from a straight section into a bend and all other factors are low or in-significant. V_{SP} is constant as the driver travels along the straight section however, 200m before the actual bend, the driver decelerates sharply as the vehicle moves into the bend.



Sample V_{SP} for a 3.5km rural road segment travelling North to South, acquired in midlands, Ireland April 2011. V_{SP} values range from good (yellow symbols), indicating reasonable road factors to poor (red symbols) indicating deteriorating road factors e.g. increasing curvature, decreasing road width and hazards.

After about 10m from the point of inflection, the vehicle begins to accelerate away. The zone of interest therefore begins where a change is observed in V_{SP} as the driver approaches the bend, 200m out and terminates when the driver begins to accelerate away. This last example lists only one factor but there may be more factors so, this proposed methodology has to be able to compare all factors perceived or otherwise against V_{SP}. This will enable single and composite factors to be compared with a proxy value for risk i.e. V_{SP} as measured by drivers' perception of risk, at any point along the network. This allows us to construct, not only a methodical approach to rapidly identify and understand risk along roads but also opens up the opportunity to discover patterns and use the associated values recorded for both the cause (road factors) and effect (V_{SP}) to calculate universal values for risk factors and associated weightings. Ranking will be based on combined anomalous V_{SP} values linked to associated factors at the same location. One of the key points is ensuring that driver perception and associated V_{SP} is neutral and can be repeated.

Level-3

The objective here is to identify factors that are not highlighted in Level-2 processing since they are either not visible or although visible are deemed to pose no significant threat by the driver. This process ignores V_{SP} and examines just the physical road elements table to identify single or groups of factors that fall outside a threshold based on some safety engineering rule or guideline e.g. curve radius less than 250m or road width < 3.1m. Table 18 repeated again below.

Factor	**Threshold Rule**
Horizontal Alignment	curves, R < 400m
	curves R <100m
	180gon/km < CCR ≤ 360gon/km
Vertical Alignment	grades <6%
	crests more dangerous than sags
Cross-section	lane width < 3.5m
	existence of a hard-shoulder < 1.3m
	cross-fall >= 2.5%
	super-elevation < 7%
Surface Condition	SFC < 0.25

Table 18. Elementary rule base for highlighting sections of road that present risk

These are highlighted as single or composite events depending on spatial proximity. These locations are then highlighted for further investigation.

The results from these three levels of processing can be combined and used to construct a risk map which can also be integrated with any datasets representing existing safety intervention. Potential risk locations can be highlighted and examined where clustering of accidents is observed or a significant change is observed in V_{SP} or a threshold for one or more factors are exceeded. This map can be viewed at any scale and queried for particular ranges of factor values or combination of factor values. Integrating existing safety interventions enables the user to inspect whether adequate protection, signage, marking are in place to ameliorate the risk posed. If we also consider V_{SP} as a typical average safe driving profile for any section along the route and compare this with risk as mapped from Level 3, as well as historic accidents together with existing safety intervention to i) acknowledge that risk is present and can be explained ii) adequate safety interventions are in place iii) V_{SP} is actually within limits. This ideal scenario would have to be tested under other transient road environment conditions including: poor illumination, deteriorating weather conditions or heavy traffic. This approach may allow safety engineers to make a more reliable and useful connection between risk, safety interventions and actual driving profile.

4.4 Discussion

The proposed framework integrates all three levels of processing and acknowledges the great challenge in attempting to measure, classify and quantify risk at a suitable spatial scale along national rural road networks. Quite a lot of research has been carried out so far but the results indicate that further work is required in order to produce a robust, universal model that can report risk to road users in a detailed, timely, consistent fashion across multiple rural road network types. This is due to complex interactions and variable nature of the dynamic road environment.

This framework provides a modelling environment where the static road factors, historic accident database and a controlled dynamic variable in the form of V_{SP} can be integrated and examined at very high spatial scales. The framework enables perceived risk (V_{SP}) to be compared with physical road parameters as well as historic collisions. It allows existing blackspots or potential blackspots to be highlighted. It provides a rapid screening tool that delineates areas along the network where risk is significant. V_{SP} is a proxy for risk and can be categorised as the perceived risk presented by a single or small number of visible risk factors. Some risk factors will be visible to the driver but may not be considered a threat so, may not affect the V_{SP} at that location. Risk factors that are not visible to the driver will not affect the outcome of V_{SP}.

Perceived risk enables the obvious features and factors that contribute to risk to be highlighted. It does not attempt to explain driver reaction or take into account multiple factors, if they do not exist at any one location, nor does it attempt to explain driver reaction time, prioritization, workload or any other cognitive processes. It is simply an attempt to use an average, safe driver profile as an indicator of perceived risk which in turn is directly linked to the majority of risk factors occurring along any stretch of rural road. The extreme opposite should result in a black-spot over time i.e. a high risk location that is not detected by V_{SP} since it does not present adequate visible cues to the driver to trigger a change in their driving profile. This scenario should become apparent after integrating all three levels of processing. V_{SP} should also be directly related to the static road factors since the survey, by definition, should be carried out under good weather, reasonable illumination and free flow conditions. Any un-usual events for example, sharp breaking due to an animal crossing the road, or poor manoeuvring by vehicle in front can be detected and removed using the data collected by the mobile mapping system.

(V_{SP}), not only provides a proxy for perceived risk but also provides information on how the road is typically driven. The velocity profile on its own when compared to network length provides an overall measure of general road safety. For example a perfectly straight road with optimal safety features should produce an optimum V_{SP}. Contrast this with the V_{SP} resulting from a rural road with many bends and lacking safety features. Including this velocity variable makes the connection between static road environment, vehicle speed and ensuing risk. The framework will also allow road factors that fail some set of safety engineering criteria e.g. bad road bend, are highlighted independent of V_{SP}. This integrated approach will allow the various risk factors to be clearly identified and compared between various locations so, that one location can be deemed to be riskier than another. The main thrust of this framework is to enable data to be collected and processed in an efficient manner and allow road network managers rapidly identify and understand risk along rural roads following an RSI.

4.5 Summary

A number of factors dealing with road geometry, surface conditions, layout and hazards underpin safety along our rural road networks in Europe. The safety engineering basis for each of these factors was described. The shortcomings of accident database were detailed as was the role this important data source has to play in risk assessment associated with an RSI. An integrated framework comprising three levels of processing was proposed cantered around accident database, static road factors and a new concept based on V_{SP}. This framework enables risk whether perceivable, visible or indeed invisible to be detected at a high spatial resolution along the network.

The proposed methodology comprises data collection using the mobile mapping system, construction of the table at a high spatial resolution, made up of historic accident data, physical road factors and V_{SP}. Level 1 processing enables any black-spots scenarios to be detected. Level-2 enables perceived risk to be rapidly highlighted using V_{SP}. Level-3 applies a rulebase in the form of scenario specific thresholds, independent of V_{SP}, to the data in order to determine if it passes or fails any specific safety engineering criteria. These results are all brought together within the framework to produce a network risk map that can also handle any data inputs of existing safety intervention. This overview map indicates locations that require further investigation, enables these locations to be compared with one another and also allows the road manager to query what factors make up risk at any location highlighted for investigation.

5 Conclusions & Recommendations

5.1 Introduction

Great emphasis is placed, within the context of road safety and road infrastructure across Europe, on both the concept of “self-explaining road” which should influence positive driver behaviour as well as the “forgiving roadside” which should protect road users by providing a variety of safety measures and modern design implementations that will reduce injury and save their lives in the event of an accident. Road Safety Inspection has an important role to play in helping implement this overall objective of making our roads more perceptive and intuitive to the driver and at the same time highlighting sections where additional safety interventions are required in order to address shortcomings in either the road infrastructure or road-side features in a timely fashion. The purpose of this study was to carry out a literature review in order to assess best practice arising from research activities in areas relevant to risk assessment within the context of Road Safety Inspection. The outputs from this report should help the EuRSI research team to formulate a methodology for carrying out an initial safety risk assessment following a RSI. This risk assessment methodology (from Chapter 1) should;

- highlight sections of road that require further investigation
- provide clear and easily accessible data to explain risk assessment at any location along the network.

5.2 Conclusions

Road user risk prevails from the start of any journey right through to the final destination. Static road risk factors can be continuous such as pavement surface condition or discrete such as road side point hazards. Risk is a relative term since it depends on the interaction of a number of static and dynamic variables. The relationships between risk factors are complex and it is difficult to compute their potential or actual contribution to an accident event. In the first instance, a systematic approach is required to highlight and explain potential risk along rural roads in an operational environment.

This study acknowledges that the task of identifying and measuring risk is non-trivial, involving a complex series of interactions centred around driver, vehicle and road environment. Road Safety Inspection is concerned, initially, with monitoring the existing physical road environment and in this study is further limited to examining certain static risk factors such as road geometry, surface condition and hazards along rural road networks.

- Modelling safety risk for all road users along rural road networks is highly complex
- Europe's approach to road infrastructure safety focuses around self-explaining roads and forgiving roadsides
- Road Safety Inspection should highlight sections of physical road environment that exhibit risk and require closer examination
- Summary of EuRSI RSI Risk Assessment methodology
    - confined to certain static road environment factors
    - highlight sections of road prone to risk
    - provide data and logic to support risk assessment for any location or section
    - relatively easy to implement & operate

Transient factors such as illumination, weather, and real time traffic flow are not considered in this study. Modelling risk along roads tends to follow either a global, generalised model or a more specific, road environment, risk-type scenario. In the former, historic accidents, road length and AADT are used to derive an overall statistical statement of risk and associated safety along road networks whilst in the latter a range of data inputs comprising factors and associated weightings are used within a relatively complex model to produce reasonable results that in most cases are highly site-specific and cannot be applied to other scenarios. It has also been noted that research initiatives, coordinated by national road authorities, for example FHWA's IHSDM crash prediction module, have been reasonably successful in bridging the gap between global and more scenario specific approaches in developing applied solutions, better suited to operational environments, where a greater range of data inputs are used to predict global outcomes.

- Generally two main risk assessment approaches reported in literature; Global based around accident, network length & AADT and scenario/site specific based on factors and associated weightings
- Road authorities have taken a more pragmatic approach and used combined features to produce a solution that can be implemented within an operational environment

The main thrust of this study focuses on a number of static elements representing the road environment however, the role of two other components also came under scrutiny during the course of this review namely the role of historic accident as well as vehicular speed. Accident data is an important input for understanding and helping assess risk but is not without some drawbacks. Vehicle velocity is recognised as having a significant contribution to both accident likelihood & severity. It can also be used to highlight perceived risk.

- Historic accident data has an important role to play in highlighting critical location of risk, associated causative factors and prioritisation of new safety interventions.
- A safe profile velocity, indicated by V_{SP} has potential to be used in helping highlight sections of (perceived) risk

RSI is meant to be an efficient, useful, rapid, inspection tool that should be easy to implement and operate in a timely fashion. EuRSI is tasked with identifying sections of road that pose risk and providing a system that enables the user to understand the factors. A novel framework incorporating three levels of processing is proposed where accident databases, static road factors and V_{SP} are integrated within one table. This enables some of the more obvious risk locations to be detected using the accident database. V_{SP} can be used as a proxy for perceived risk to highlight locations that require further inspection. Level-3 processing tests the table against a set of threshold rules to identify risk that may not be perceived as a threat by V_{SP} or simply not visible to the driver. These results can be compared with a record of existing safety interventions in the form of protection mechanisms, markings and signage.

- A framework incorporating three levels of processing based on accident database, a safe profile velocity V_{SP} and a number of static road factors can help detect and explain risk in a timely fashion
- The emphasis in this project is devising a methodology that highlights risk, allows the user to query why the location was highlighted, enables some level of comparison of risk locations along the network, and can be deployed in an operational environment

5.3 Recommendations

This report proposes a number of key recommendations dealing with definition of risk assessment and the roles of accident database, statistical modelling & vehicular velocity within the context of formulating an overall framework for risk assessment following a Road Safety Inspection.

- Risk Assessment in the context of RSI needs to be defined. One proposed definition;

  - A risk assessment methodology associated with an RSI should be able to highlight and explain the main sources of risk along any rural road network in a timely, concise, robust fashion based on safety engineering principles. Risk assessment should confine itself to assessing the risk associated with the static physical road factors including geometry, road-side features and surface condition. Data sources should include those acquired and derived from mobile mapping systems and accident databases. Particular attention should be paid to the role of vehicular velocity in assessing risk.

- Accident database
    - Accident databases contain very useful historic data that has a role in risk assessment in RSI but contains a number of shortcomings when used to model risk. It is reasonable to assume that in some cases that it may be impossible to record the actual factors that caused the accident in any meaningful way. Additional shortcomings include poorly structured databases, incomplete or missing data resulting in difficulty in interpreting the actual factors in any accident. In the context of an RSI, accident databases can be used to highlight locations that are an obviously high-risk, identified by the number and severity of accidents. Accident data can also be used to help prioritise remedial actions by the Network Safety Manager.

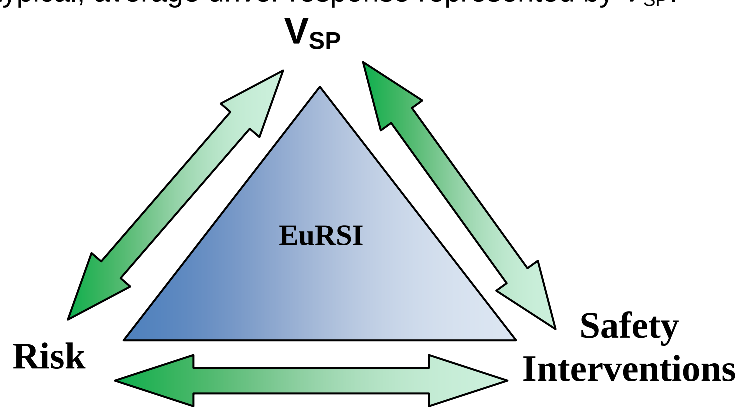
- Statistical Modelling
    - Statistical modelling can be broadly grouped into global and more localised, collision specific accident prediction or safety risk modelling. Research in this area is quite active and some recent notable outputs includes complex modelling by Cafiso et al. (2010) and Turner et al. (2011), described in more detail in Appendix 7.2. Comprehensive safety risk systems used in operational environments includes FHWA Interactive Highway Safety Design Model Crash Prediction Module and AARB's Road Safety Risk Manager. These systems, in particular the FHWA IHSDM CPM are reasonably complex and quite detailed. The advantages of statistical modeling within safety risk assessment are countered by the complexity and often site or scenario specific nature of the results produced by these algorithms. The scope of this project does not allow for additional time to investigate these methodologies any further. Further work is required in this area to assess whether the general approach and associated methodologies developed by contemporary research projects and national systems could have any significant impact to European RSI. The initial approach to risk assessment within the context of RSI here in Europe should concentrate on designing a system where risk can be detected in a timely and

robust fashion and then explained in a meaningful way to the road safety engineer.

- Safe profile velocity V_{SP}
    - o A new factor, safe profile velocity V_{SP}, is proposed. This data is recorded using onboard GPS under typical (daylight, fair weather, free-flow) conditions, ideally, at the same time as the mobile mapping system data-acquisition. The driver is instructed to drive so as to ensure a safe, comfortable profile over the entire survey section. V_{SP} can be used as a proxy for perceived risk of the associated static road factors, as measured by the mobile mapping system. V_{SP} should be repeatable.

- RSI Risk Assessment Framework
    - o A novel framework is proposed for risk assessment in the context of RSI incorporating data from accident database, V_{SP}, and road factors. Three integrated levels of processing ensure that safety risk can be detected and explained using an evidence based safety engineering system. Existing safety interventions can be incorporated to determine whether any risk posed is adequately managed and ameliorated.

Perhaps, the most important output of this risk assessment study, within the context of Road Safety Inspection across Europe, is the attempt to make the connection between detectable road risk factors, road safety intervention and safe driving behaviour as observed from V_{SP}. Risk factors, as they pertain to RSI, can be discrete or continuous, static or transient, singular or multiple but the overall interaction is dynamic in nature. Relating a dynamic driving profile to both risk posed to road users and safety interventions implemented by network operators allows the road safety engineer to consider all aspects of the dynamic risk model within the scope of RSI namely: risk whether perceived or not (likelihood, severity, exposure), mitigation (safety features in place or required) together with the everyday, typical, average driver response represented by V_{SP}.



These three quantities have a reciprocal relationship where one is influenced by or, in turn, determines the other. Varying one will usually produce a change in the other two. This dynamic model varies geographically but the relationship between the three quantities still holds. This enables locations that require closer attention along the network to be detected as well as providing a better insight into the overall inter-relationship of Risk, Safety Interventions and driver behaviour at that location. Risk assessment in the context of RSI needs to be considered within this dynamic relationship model.

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7 Appendix

7.1 Extracts from Checklists for Austrian Rural Roads

RSI Check List for rural roads		Relevance for safety		
		High	Mid	Low
A DESIGN PARAMETERS				
A1 Road segment				
Layout	defect:			
	problem:			
Longitudinal section (geometry)	defect:			
	problem:			
Topology layout	defect:			
	problem:			
Cross section	defect:			
	problem:			
Visibility	defect:			
	problem:			
Drainage	defect:			
	problem:			
Cross roads	defect:			
	problem:			
Land gateway	defect:			
	problem:			
Station	defect:			
	problem:			
A2 Service/frontage roads	defect:			
	problem:			
A3 City entering/exits	defect:			
	problem:			
A4 Railway crossing	defect:			
	problem:			
B ROAD SURFACE	defect:			
	problem:			
C LIGHT CONDITIONS	defect:			
	problem:			

D TRAFFIC CONTROL DEVICES				
D1 Traffic signs/destination signs	defect:			
	problem:			
D2 Road markings	defect:			
	problem:			
D3 Plants	defect:			
	problem:			
D4 Crash barrier	defect:			
	problem:			
D5 Wild life protection	defect:			
	problem:			
D6 Traffic light	defect:			
	problem:			
D7 Crossings	defect:			
	problem:			
E SURROUNDING OF ROAD	defect:			
	problem:			
E1 External infrastructure	defect:			
	problem:			
Y ANALYSIS OF TRAFFIC OPERATIONS	defect:			
	problem:			
Z ACCIDENTS	defect:			
	problem:			

		curve radius [m]		
layout drawing		V_{85} [km/h]	deficit[9]	no deficit
		60	< 120m	≥ 120m
		80	< 250m	≥ 250m
		100	< 450m	≥ 450m
longitudinal section	gradient	gradient (s [%])[4]		
		V_{85} [km/h]	deficit	no deficit
		60	> 10%	≤ 10%[3]
		80	> 8%	≤ 8%[3]

		100	> 6%	≤ 6%[3]
	cross fall	cross fall in straight line [q]		
		V_{85} [km/h]	deficit[5]	no deficit
		60	< 2,5%	2,5%
		80	< 2,5%	2,5%
		100	< 2,5%	2,5%
		cross fall in arch [q]		
		V_{85} [km/h]	deficit[6, 7]	no deficit
		60	q<2,5% & q>7%	2,5% - 7%
		80	q<2,5% & q>7%	2,5% - 7%
		100	q<2,5% & q>7%	2,5% - 7%
		cross fall depending of curve radius		
		R [m]	deficit[6]	no deficit[8]
		≤ 400	q<2,5%	2,5 - 7%
		500	q<2,5%	2,5 - 5,5%
		600	q<2,5%	2,5 - 5%
		700	q<2,5%	2,5 - 4,5%
		800	q<2,5%	2,5 - 4%
		900	q<2,5%	2,5 - 3,5%
		1000	q<2,5%	2,5 - 3%
		≥ 1200	q<2,5%	2,5%
		cross fall transition area		
			deficit[21]	no deficit
			s^{22} - Δs^{23} ≤ 0,5 %	s - Δs ≥ 0,5%
	line of max. slope	cross fall depending of gradient		
		s [%]	deficit	no deficit
		≤ 4	> 7%	2,5% - 7%
		5	> 6%	2,5% - 6%
		6	> 5%	2,5% - 5%
		≥ 7	> 3,5%	2,5% - 3,5%
visibility		overtaking sight distance [m]		
		V_{85} [km/h]	deficit[1]	no deficit
		60	< 475m	≥ 475m
		80	< 525m	≥ 525m
		100	< 625m	≥ 625m
		stopping sight distance [m]		
		V_{85} [km/h]	deficit[2]	no deficit
		60	< 65m	≥ 65m
		80	< 110m	≥ 110m

	100	< 170m	≥ 170m
cross-section	width of traffic lane [m] [10]		
	V_{85} [km/h]	deficit[11]	no deficit
	60	< 3m	≥ 3m
	80	< 3,25m	≥ 3,25m
	100	< 3,50m	≥ 3,50m
	width of edge strip		
	width traffic lane [m]	deficit[12]	no deficit
	< 6,50	< 0,25m	≥ 0,25m
	≥ 6,5m	< 0,50m	≥ 0,50m
	width of shoulder (outer soft shoulder)		
	width traffic lane [m]	deficit[13]	no deficit
	< 7,0m	< 0,25m	≥ 0,25m
	≥ 7,0m	< 0,50m	≥ 0,50m
	width of pedestrian- and cycle ways		
	width [m]	deficit[20]	no deficit
	pedestrian way	< 2,0m	≥ 2,0m
	cycle way	< 2,5m	≥ 2,5m
	shared pedestrian and cycle way	< 3,0m	≥ 3,0m

road surface		**skid resistance [μ]**		
			deficit[14]	no deficit
		skid resistance [μ]	≤ 0,45	> 0,45
		depth of lane grooves [mm]	≥ 15mm	< 15mm
		thickness of water on the road surface [mm]	≥ 4mm	< 4 mm
roadside equipment	traffic signage	**road signage (visibility)**		
		V_{85} [km/h]	deficit[17]	no deficit
		60	visibility < 75m	≥ 75m
		80	visibility < 100m	≥ 100m
		100	visibility < 125m	≥ 125m
		road signs (lateral distance and high)		
			deficit	no deficit[18, 19]
		lateral distance of road	< 1,0m & > 2,5m	1,0m - 2,5m
		high distance over the road	< 4,5m & > 5,5m	4,5m - 5,5m
	line marking	**line marking**		
			deficit	no deficit
		edge line	missing or inadequate	available & visible
		center line	missing or inadequate	available & visible
	crash barriers	**trees**		
		V_{85} [km/h]	deficit	no deficit
		60	-	-
		80 100	existing crash barrier at trees (diameter > 100mm) in a distance from 6m from the border paves surface	crash barrier not existing
		signage, rigid obstacles		
		V_{85} [km/h]	deficit[15]	no deficit
		60	-	-
		80 100	existing crash barrier at post > 76mm	crash barrier not existing
		embankment		
		V_{85} [km/h]	deficit[16]	no deficit
		60	-	-
		80 100	existing crash barrier at abrupt embankment with falling gradient > 1:3, altitude > 3m	crash barrier not existing

bridge, undergrade crossing, noise barrier		
V_{85} [km/h]	deficit	no deficit
60	crash barrier existing	crash barrier not existing
80		
100		

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[1] minimum overtaking sight distance, Forschungsgesellschaft für Straßen- und Verkehrswesen: RAS-L, 1995,p. 25
Zimmermann, Roos, article in: Straße + Autobahn 2.2002, p. 67
[2] minimum stopping sight distance, Forschungsgesellschaft für Straßen- und Verkehrswesen: RAS-L, 1995, p. 24
Zimmermann, Roos, article in: Straße + Autobahn 2.2002, p. 67
[3] maximum gradient, Österreichische Forschungsgesellschaft Straße-Schiene-Verkehr, RVS 03.03.23, 1997, p. 2
[4] gradient till s=0% is acceptable if cross fall is not < 2,5% and therefore the surface drainage is provided (cf. Österreichische Forschungsgesellschaft Straße-Schiene-Verkehr, RVS 03.03.23, p.2)
[5] minimum and standard cross fall, Forschungsgesellschaft für Straßen- und Verkehrswesen: RAS-L, 1995,Blatt 19
generally shall be provided one-sided cross fall
[6] minimum cross fall [q_{min}], Forschungsgesellschaft für Straßen- und Verkehrswesen: RAS-L, 1995, p.19 at all area of road with angle of twist q<2,5% must be minimum gradient s ≥ 0,3%
[7] maximum cross fall [q_{max}], Österreichische Forschungsgesellschaft Straße-Schiene-Verkehr, RVS 03.03.23, 1997, p. 2
[8] when implementation of the maximum crossfall [q_{max}] is not possible then shall be implemented the highest possible cross fall, Österreichische Forschungsgesellschaft Straße-Schiene-Verkehr, RVS 03.03.23, 1997, p. 2
[9] minimum curve radius [r_{min}], Forschungsgesellschaft für Straßen- und Verkehrswesen: RAS-L, 1995, p.8
[10] width of traffic lane at rural roads with upper traffic volumes
[11] Österreichische Forschungsgesellschaft Straße-Schiene-Verkehr, RVS 03.03.31, 2005, p. 5
[12] Österreichische Forschungsgesellschaft Straße-Schiene-Verkehr, RVS 03.03.31, 2005, p. 5
[13] Österreichische Forschungsgesellschaft Straße-Schiene-Verkehr, RVS 03.03.31, 2005, p. 6
[14] Österreichische Forschungsgesellschaft Straße-Schiene-Verkehr, RVS 13.01.15, 2006, p.1
[15] Forschungsgesellschaft für Straßen- und Verkehrswesen: RPS, 1989, p.3
[16] Forschungsgesellschaft für Straßen- und Verkehrswesen: RPS, 1989, p.3
[17] readingtime 4,5 sec.
[18] Österreichische Forschungsgesellschaft Straße-Schiene-Verkehr, RVS 05.02.11, 2006, p.9
[19] Österreichische Forschungsgesellschaft Straße-Schiene-Verkehr, RVS 05.02.11, 2006, p.10
[20] Forschungsgesellschaft für Straßen- und Verkehrswesen: RAS-Q, 1996, p.6
[21] Forschungsgesellschaft für Straßen- und Verkehrswesen: RAS-Q, 1996, p.11
[22] gradient
[23] “Anrampungsneigung” (difference between gradients road surface edge and centre rotation axis)

7.2 Statistical Modelling

Two examples of stat of the art risk assessment methodologies are presented in this section. These two examples demonstate the challenges and complexity of risk assessment in an operational environment. These are based on state of the art crash prediction model development resulting from the literature review in Chapters 2. The first methodology evaluated by Cafiso et al., (2010) is based on the Generalized Linear Modeling approach (GLM), which is reported has having 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, Cafiso et al., (2010).

The general form of the accident prediction model adopted is:

$$E(Y) = e^{a0} \cdot L \cdot AADT^{a1} \cdot e^{\sum_{j=1}^{m} bjxj}$$

Where;

E(Y) is the expected injury accident frequency/year
L is the length of the segment under consideration (km)
AADT is the Average Annual Daily Traffic (AADT) (veh/day)
x_j is the any of m-additional variables
a_0, a_1, and b_j are the model parameters.

This model is generally accepted and logically estimates zero accidents if one of the two exposure variables (AADT or L) is equal to zero, Cafiso et al., (2010). Table 8 details a statistics summary of the variables derived from risk factor data examined by Cafiso et al., 2010 when considering accident prediction model development. Cafiso et al., (2010) reported that final selection of variables was based on an initial analysis to identify the correlation between two independent variables among those reported in Table 10 below. The most common measure of correlation is the Pearson Product Moment Correlation (Pearson's correlation (CP)) (Pearson, 1896) which reflects the degree of linear relationship between two variables, with values of +1 or −1 indicating perfect positive or negative linear correlation, respectively.

Variable group	Abbreviation	Description	Mean	Min.	Max.	Standard deviation
Exposure	L_{HS} [km]	Length of homogeneous section	1.57	0.50	4.29	0.83
	AADT [veh/day]	Average Annual Daily Traffic	3811	600	12,400	2520
Geometric and operational	CCR_{sect} [gon/km]	Section curvature change rate	114.79	0.00	629.21	128.85
	W [m]	Paved width	7.33	5.70	10.00	1.22
	TR	Tangent ratio	0.38	0.04	1.00	0.27
	CR	Curve ratio	0.31	0.00	0.71	0.18
	V_{avg} [km/h]	Average operating speed	92.8	57.5	115.5	15.5
Consistency	R_a [m/s]	Relative area bounded by the speed profile	1.23	0.00	4.06	0.95
	σ [km/h]	Standard deviation of operating speed profile	6.98	0.00	18.46	5.13
	ΔV_n [km/h]	Average speed differential	10.16	.00	28.63	6.68
	ΔV_{10} [no./km]	Speed differentials density (higher than 10 km/h) in the Homogeneous section	2.94	0.00	14.30	3.53
	ΔV_{20} [no./km]	Speed differentials density (higher than 20 km/h) in the homogeneous section	1.40	0.00	12.55	2.30
Context-related	RSH	Roadside hazard	1.52	0.00	4.93	1.07
	DD[n driveways/km]	Driveway density	6.77	0.80	21.81	4.64

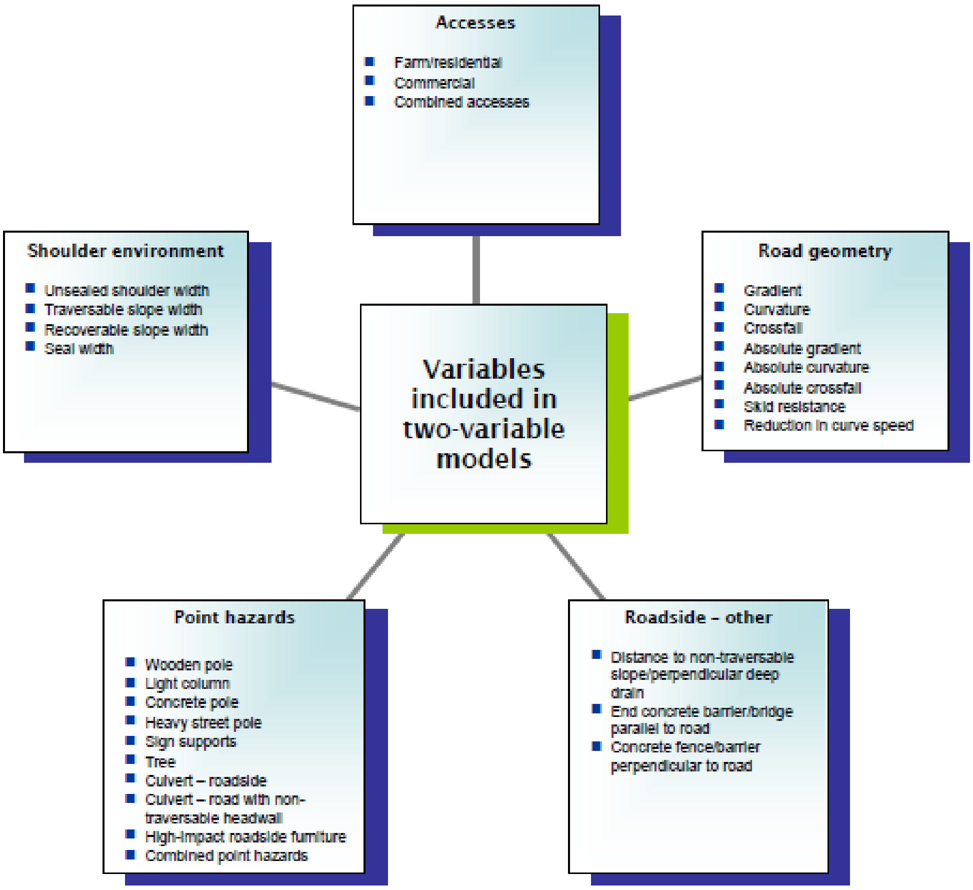
Summary of characteristics of homogeneous section variables considered for model development (after Cafiso et al., 2010)

Three models were short-listed based on practical considerations, statistical significance and goodness of fit;

- Model 1 includes only the exposure variables, length (L_{HS}) 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 (L_{HS}), traffic volume (AADT), driveway density (DD), roadside hazard rating (RSH), curvature ratio (CR) and number of speed differentials higher than 10 km/h (ΔV_{10}).

Cafiso et al., (2010) report that Model 1 can be applied in an Empirical Bayes procedure to conduct network screening analysis since non-exposure variables are unlikely to be readily available for the entire network. Models 15 and 19, which have the best fits and at least one variable pertaining to the four main groups of variables (exposure, geometric, consistency and context), can be used to evaluate the safety performance of existing roads or alternative design improvement solutions. From a pragmatic perspective, Model 19 may be preferable to Model 15 since, in addition to the driveway density variable, it includes roadside hazard (a variable evidently related to the accident severity based on previous research). It is also easier to apply than Model 15, which requires the determination of the standard deviation of speed (s) based on an operating speed profile. By contrast, for the computation of the number of speed differentials higher than 10 km/h (∆V10) for Model 19, it is enough to obtain the measurements between contiguous elements (curves and tangents) along a homogeneous section, Cafiso et al., 2010.

The second statistical approach results from a detailed investigation into next generation rural road crash prediction models carried out by Turner et al., (2011). This Generalised Linear Regression model is related to work by Cafiso et al., (2010) above where factor type and factor combination were examined. Along with traffic volume, twenty-eight other predictor variables divided into five categories were examined.



28 original predictor variables (after Turner at al., 2011)

From those 28 variables, a most-representative and best-performing set of eight was selected to be incorporated into the multi-variable models alongside traffic volume, based on the results of the two-variable models. The variables that were found to perform the best were:

The variables that were found to perform the best were:

- unsealed shoulder width
- seal width
- combined point hazards

- combined accesses
- distance to non-traversable slope/perpendicular deep drain
- absolute gradient
- absolute curvature
- SCRIM coefficient.

In addition, a horizontal alignment variable (percentage reduction in curve speed) was added to the best-performing variables in the above list, in order to develop a more robust model. Out of the nine variables listed above, the overall preferred model was found to involve volume, distance to non-traversable hazard, absolute gradient, SCRIM coefficient, and percentage reduction in curve speed.

A number of multivariable models were tested and one based around a five variable input was chosen. Some caution is advised since the authors state that this model was developed and tested using a relatively small sample size and so, not suitable for general use.

4 variable Model	5-variable Model	6-variable Model
Traffic Volume (V)	Traffic Volume (V)	Traffic Volume (V)
Non-traversable Slope / Perpendicular Deep Drain (N)	Non-traversable Slope / Perpendicular Deep Drain (N)	Non-traversable Slope / Perpendicular Deep Drain (N)
Skid Resistance (Sr)	Skid Resistance (Sr)	Skid Resistance (Sr)
Absolute Gradient (G)	Absolute Gradient (G)	Absolute Gradient (G)
	% Reduction in curve speed (Vc)	Combined Accesses (Ca)
		% Reduction in curve speed (Vc)

Multi-variable model (after Turner et al., 2011)

The preferred model had the following form:

$$A = 2.2E^{-04}\ V^{0.719} \times N^{0.078} \times G^{-0.26} \times Sr^{-2.569} \times Vc^{0.219}$$

where:

A is the predicted number of crashes in five years for a 100m section of rural road

V is the two-way AADT for the road section

N is the distance in metres to the non-traversable hazard (e.g. row of trees or deep ditch), multiplied by 1000.

G is the absolute gradient

Sr is the average value of SCRIM for the road section

Vc is the percentage reduction in the curve-negotiation speed of the section as compared with the preceding 500m section

Handling un-certainty

Elvik (2010) finds that road safety policy is made in great uncertainty and that it is not always perfectly clear which group of accidents or road users a road safety measure influences. He concluded;

- The targets for improving road safety as part of national road safety programmes are not always realised. One reason for this may be that sources of uncertainty in the estimated impacts of such programmes are overlooked.
- Ten sources of uncertainty in estimated benefits of national road safety programmes were identified and described. Five of these sources can be quantified, whereas too little is known to quantify the other five sources of uncertainty.
- Uncertainty with respect to the impacts of road safety programmes is rarely estimated, but is likely to be considerable.
- More research on sources of uncertainty in road safety programmes may lead to the quantification of more sources of uncertainty, but it is unlikely that all sources of uncertainty can ever be meaningfully quantified.

Estimates of the effects of road safety measures are always uncertain; the more so when several measures are combined in a programme. The monetary valuation of the benefits of road safety measures is highly uncertain; thus it may not be possible to determine the optimal level of safety. No road safety programme can influence road safety more than marginally; road safety is influenced by a host of factors that are beyond the control of any national, not to say local, government.