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Ph.D. Thesis

Road Traffic Safety Framework

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Kurzfassung

Sicherheit im Straßenverkehr ist ein wichtiges Thema, mit dem Ziel, die Anzahl der Unfälle und die der daraus resultierenden Verletzungen und insbesondere Todesfälle zu verringern. Ein wichtiger Aspekt dabei ist der Zustand der Straße, da diese sowohl Unfälle verursachen, als auch die Folgen eines Unfalles verschlimmern kann. In diesem Bereich der Verkehrssicherheitsforschung werden Computertechnologien jedoch nur in einem geringen Ausmaß eingesetzt.

In dieser Arbeit wird ein Straßenverkehrssicherheits-Framework eingeführt, dass Methoden und Technologien aus der Informatik einsetzt, um für die Forschung und Entwicklung relevante Daten zu erfassen, diese effektiv zu speichern und sowohl für administrative Zwecke, als auch für die Forschung zu instrumentalisieren.

Bei der Datenerfassung ist die wichtigste Datenquelle der Straßenzustand. Dieser wird mittels sogenannten Road Safety Inspections (RSI) erfasst. Diese Untersuchengen werden zum Großteil manuell durchgeführt. Hier wurde eine Software entwickelt, mit der RSI's computergestützt durchgeführt werden können, was einerseits die Kosten senkt, andererseits viel genauere und vor allem elektronisch weiterverarbeitbare Daten liefert.

Zum speichern dieser Daten und zum verknüpfen mit anderen wichtigen Daten wie Wetter-, Unfall- oder Verkehrskonfliktdaten, ist ein Data Warehouse vorgesehen. Ein Data Warehouse ist eine auf Analysen ausgelegte Datenbank, die insbesondere in der Industrie zur Marktforschung eingesetzt wird.

Der Einsatz eines Data Warehouse bringt neue Möglichkeiten für die Verkehrssicherheitsforschung, die in dieser Dissertation anhand umfangreicher Unfalldaten aus den USA demonstriert werden. Einerseits werden fünf bekannte Hypothesen untersucht, wobei sich vor allem die Wichtigkeit von aktuellen Daten kennzeichnet. Andererseits werden die vorhandenen Daten mittels einer statistischen Methode automatisch untersucht, um unbekanntes Wissen zu finden, ohne dass vorher eine Hypothese definiert werden muss.

Die Dissertation schliesst mit der Empfehlung ab, dass Informatiker und Verkehrsplaner viel mehr zusammenarbeiten sollten, wobei die Implementierung des eingeführten Frameworks einen Startpunkt für diese Kooperation darstellt.

Abstract

Road safety is an important issue, with the aim to reduce the number of accidents, resulting injuries and fatalities in particular. An important aspect hereby is the condition of the road, because they can cause accidents and can also aggravate the consequences of an accident. In this area of road safety research, computer technologies are currently used only on a small scale.

In this work, a road safety framework is introduced that uses methods and technologies from Computer Science to capture relevant data for research and development and to store it effectively, both for administrative as well as research purposes.

During data acquisition, the road condition presents the primary source of information. This is captured by performing so-called Road Safety Inspections (RSI), which are generally being carried out manually. During the course of this thesis, a software has been developed to enable computer-aided RSI's, thereby helping to reduce the costs and to provide much more accurate data that is most importantly easy to process.

To save this data and to link it to other important data such as weather, accident or traffic-conflict data, a Data Warehouse is needed. A Data Warehouse is a database designed for analysis, which is used especially by the industry for market research. The use of a Data Warehouse brings about new opportunities for road safety research, some of which are demonstrated in this thesis using extensive accident data from the U.S.. On the one hand, five well-known hypotheses were examined that made clear the importance of current (updated) data. On the other hand, the existing data was automatically analyzed using a statistical method to obtain previously unknown knowledge, without the need to define a hypothesis prior to the analysis.

The thesis concludes with the recommendation that computer scientists and traffic planners should work together, whereas the implementation of the introduced framework is definitely a starting point for such a cooperation.

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CHAPTER 1

1 Introduction

Traffic is considered to be one of the most dangerous places in the world. So it is understandably a common goal to increase the safety of road traffic systems. The human, the vehicle, and the road are the three factors that affect road traffic safety. There are many studies that analyse how these factors interact with each other and to which extent they affect the safety of the overall road traffic system.

The road can influence the safety in two ways. On the one hand, the geometry or the condition of the road can induce hazards that may lead to accidents, while on the other hand, unsafe elements on the road and its surroundings, such as unguarded traffic signs, can worsen the results of accidents. To make roads safer, it is essential to identify and understand such safety deficiencies that cause accidents.

To make detailed studies with comprehensive results possible, it is essential to have enough data about all relevant aspects. In many profit oriented fields, like the market economy or the health sector, modern information technologies are widely used to gather all the data that could possibly be useful for any kind of analysis. In service oriented fields however, where most of the work is public funded, like road planning, there is a deficit regarding the utilization of information technologies.

The goal of this thesis is to encourage computer scientists to consider road planning as a possible area of expertise and application with much work to do and great potential, on the one hand, and on the other hand, to show road planners, what is possible with today's information technologies and to motivate them to work together with computer scientists.

Because this thesis is targeting two different scientific areas, Computer Science and Traffic Safety, some terms should be declared at this point to prevent misunderstandings.

Traffic: Through the thesis the word traffic is used always with the meaning of road traffic by motorized vehicles. Other forms of traffic such air traffic or railway traffic are named explicitly as those.
Road: Like above, this word means always a traffic road, if not stated explicitly otherwise.
Data Warehouse: A Data Warehouse is an extended database that stores data not in a relational way, but in a transactional way. Data warehouses are widely used to store and analyse information about business transactions and are optimized for this purpose.
Framework: A framework can be considered as a set of tools, methods, rules and recommendations that work together to achieve one goal.

1.1 Hypotheses and Methodology

Throughout the thesis, the research in the field of Road Planning is considered from a data driven point of view, where the main steps can be defined as data gathering, data storing and data utilization. The storage of data is a relatively standard task by now and the details of which are of no particular relevance for road planning. The focus of this thesis will be mainly on the gathering and utilization of data.

For this purpose, the Road Traffic Safety Framework will be introduced, which can be considered as a set of methods and tools that are required to easily gather data and to utilize it in an optimal way.

Accident data is acquired as part of the executive process directly on the spot of the accident and is therefore the widest available and most accurate data relevant to road safety. This accident data is used for several analyses but is alone not sufficient to perform detailed road safety analyses. As a result much research in the field of road safety is carried out locally on a small area or a certain spot and is very time and cost consuming.

An important method to gather relevant data about the road, its surrounding and their conditions are Road Safety Inspections (RSIs). In theory, it is intended to perform RSI on the whole road traffic network, every two to four years. In practice however, due to the complexity of the task and the high costs, RSI's are most likely performed on small sections of the road network with a higher accident rate only.

Therefore, RSI has been selected as a candidate for improvement that would benefit from the utilization of information technologies. In co-operation with a civil engineering office that carries out RSIs in Austria, the internal steps of such an inspection will be analyzed in detail with the goal to develop a computer software that covers the complete process of a RSI in order to perform inspections for the complete higher road network in Austria feasible. Related to road safety inspections, an important research issue is to evaluate the inspected roads and build safety maps that depict the safety score of different roads in a country. As a contribution to this research area a further goal is to outline a new evaluation method that considers the results of road safety inspections.

There are two possible options to utilize data for scientific research purposes. First, a pre-formulated given hypothesis can be proven or disproven and second, statistical methods can be used to extract information from the data. The utilization of data for research to proof road traffic related hypotheses and to extract information, highly depends on the amount of the existing data available. Because the targeted amount of data is not available yet, accident data from the US will be used to demonstrate the potential of the introduced Road Traffic Safety Framework.

For the first option, a software tool is needed that allows the researcher to easily navigate through the given data and compute and detect dependencies between different attributes. Actually a data warehouse meets these exact requirements, but it works mostly like a black box presenting only the results to the user. Further it is very complex to set up a data warehouse for a new field and to build one is therefore out of the scope of this thesis. As a substitute a relatively simple tool that implements some basic functionalities of DWH will be developed to demonstrate on one side, how researchers would benefit from the framework and on the other side, allow an insight into the operating principles. Several well known hypotheses from the field of Road Traffic Safety will be reviewed with this tool using the mentioned accident data from the US.

For the second option, the introduced framework has to be able of acquiring new knowledge out of given data. For the same reasons stated above, a tool will be developed that implements cross checking to analyze the accident data from the US. Cross checking is statistical method, where for each parameter (age, gender etc.) its distribution for all possible combinations of the other parameters is computed. Unusual divergence values that are found using this method are in general good candidates for unknown dependencies and should be further investigated.

Based on the results of these demonstrations the thesis will conclude with some suggestions on how information technologies can be used in the field of road traffic safety research and which potential the introduced Road Traffic Safety Framework has to improve and simplify the work of road traffic safety researchers, road safety inspectors and road planners and to contribute to the enhancement of Road Traffic Safety in general.

1.2 Structure of the Thesis

Chapter 2 – Road Traffic Safety: consists of an introduction to the field of Road Traffic Safety. A brief overview of the factors that affect Road Traffic Safety and improvement methods to increase it are also explained in this chapter.

Chapter 3 – Road Safety Assessment: presents the state-of-the-art of several reactive and preventive methods used for Road Safety Assessment: Black Spot Management, Network Safety Management, Traffic Conflict Technique, and Road Safety Inspections. Further, several particular projects from these fields that are relevant for the thesis are introduced.

Chapter 4 – Road Traffic Safety Framework: contains the description of our framework as the theoretical contribution of our research. The framework, divided into the three main parts of data gathering, data storage, and data utilisation, is described here in detail. Afterwards, a guideline for the implementation of the complete framework is given with respective estimations of the expected costs and benefits, including suggestions for the respective authorities.

Chapter 5 – Computer-aided Road Safety Inspection: contains the description and evaluation results of our developed RSI-Software. This computer-aided Road Safety Inspection System is part of our proposed framework. An extensive description of the actual practices in Austria is given, with a special focus on their disadvantages and the improvements our system brings about. The chapter is finished by the new road evaluation method that builds up on the RSI-Software.

Chapter 6 – Computer-aided Research: contains the results of the performed research using modern computer technologies. The results are relevant both, as a contribution to the work of road planners and as a demonstration of the possibilities the framework will facilitate for researchers.

Chapter 7 – Outlook: contains a short resume of the thesis and an outlook for future work. Further recommendations to researchers and authorities are given.

Chapter 8 – Summary: contains the summary of the thesis.

CHAPTER 2

2 Road Traffic Safety

Human beings always strived for mobility. Of course, the means to achieve mobility changed and/or advanced in accordance with the technological progress. However, one can say that there always have been several elements involved in the transportation process and security was ensured by taking the nature of those elements into consideration while planning and building the transportation networks.

With the early transportation networks there were the human beings, obviously, as the users and main benefiters from secure networks, the means they have used, that is their own feet and animals of different constitution, which they herd or rode, and the roads on which they travelled, which were mostly worn-out paths that came to be simply through frequent usage. By and by carriages were attached to the animals and mechanical but non-motorised vehicles were invented, thus changing the shape of transportation networks, because the roads had to be adjusted in order to enable the smooth locomotion of the new vehicles. As the users of the transportation networks grew bigger and were able to move faster, new security risks became part of every-day live. With the invention of motorised vehicles and their acceptance in transportation networks, these risks increased immensely. And finally, the advances in aviation resulted in a differentiation between transportation networks on the ground and in the air.

This work is about organised road transportation networks which are referred to as *Road Traffic System* throughout this thesis. In general, today's road traffic system comprises the following components/elements:

- Human beings: as drivers of the vehicles or pedestrians
- Road and its environment: as the connecting routes of the transportation network and their surroundings
- Vehicles: motorized or non-motorized vehicles as means of transportation

Traffic is, in general, organised in order to regulate the interactions between the components of a road traffic system to increase efficiency and road safety. A systematic view of the road traffic system in undertaking these regulations is essential, as each component affects the overall system differently and therefore requires different approaches.

The organisation of the road component for example, includes the categorisation of roads into different types (e.g., roads for heavy vehicles, pedestrians, etc.), the identification of lanes, the placement of signals and so on.

Organising and regulating the interactions between the components of a road traffic system also includes the generation and administration of traffic rules like priority regulation rules at certain points or intervals of the road (e.g., intersections, etc.), speed limits, and so forth.

In this chapter the many aspects of road traffic safety and how it can be improved, in terms of the factors that affect it are examined.

2.1 Factors Affecting Road Traffic Safety

The traffic safety performance depends on the smooth and safe interaction of its elements. Problems in this interaction result in traffic conflicts of different severities and in crashes in the worst case. Thus, traffic safety is sometimes defined as the state in which on a certain road section no, few, or only light accidents occur [Risser et al., 1991, p. 23]. Consequently to ensure and increase traffic safety means to prevent crashes and to reduce the severity of accidents to an absolute minimum.

To do that one first have to determine what factors affect traffic safety. Many a research study has been done to answer this question and to find out whether a certain factor, believed to be indicative of a road's safety or unsafety, indeed had the assumed effect. In an early study on British and American crash reports, for instance, Rumar [1985] reported that 57% of crashes were due solely to driver factors, 3% solely to roadway factors, 2% solely to vehicle factors, 27% to combined roadway and driver factors, 6% to combined vehicle and driver factors, 1% to combined roadway and vehicle factors, and 3% to combined roadway, driver, and vehicle factors. In this section we are going to analyse these three factors in more detail.

[Ogden, 1996, p. 12] argues that to approach accidents based in notions of cause and blame is simplistic in the extreme. [Leeming, 1969, p. 102] was one of the first to state that drivers were not the main cause of many road safety problems, with the conviction that road casualties could be reduced by using road engineering methods based on evidence derived from the scientific analysis of the causes of road accidents.

In order to understand these factors and their effects on traffic safety better, they are examined in this subsection in more detail.

2.1.1 The Human Factor

The primary factor affecting traffic safety is the human being, that is, the drivers and other road users, such as pedestrians. Hobbs [1987, p. 494] reported that the chain of events that lead to 90% of all accidents, contain human error and law violations they undertake. The human being is a complex and somewhat unpredictable creature as far as their actions and reactions on the road are concerned, so that besides their physical condition and their general attitude towards secure driving, also their psychological condition while driving comes into play.

The *physical condition* of the driver has to allow him to receive and process the information he is confronted with correctly and without bias and, of course, has to allow him to undertake appropriate actions. To assess this aspect of a driver is not that difficult, as physical handicaps and the use of intoxicants are easily identified.

The *general attitude* towards secure driving is more complicated to assess. When asked directly, most of the drivers would say that they are good drivers and drive safely. There might be nothing wrong with this kind of statements, but sometimes a certain level of arrogance can be sensed. So much so that on further investigation one can observe that drivers often think that they are „better“ drivers than „the others" and that by implication they have the right to violate some of the regulations, because, apparently they are meant for „less“ good drivers anyway. It is also interesting to note that drivers who have a clean record tend to grove in confidence over time and consequently begin to drive less carefully.

Similarly the *psychological condition* of the driver is hard to assess, as many things can occupy the mind of a human being at the same time and many feelings can grove and erode in oneself within very small fractions of time. It is understandably difficult for the driver to recollect what was going through his mind before or just before an accident happened.

Some other conditions that may cause human error and lead to collisions are:

- External environmental conditions: limitations of vision, etc.
- Distractions: phone calls, conversation, etc.
- Overload or underload
- Insufficient interaction and reaction time
- Unfamiliar environment
- Lack of adequate skills or training

In short, human beings are likely to err because of some reason or the other, in road traffic systems as anywhere else. However, according to [Leeming, 1969] it is wrong to put the blame of accidents fully on the driver. He argued that this kind of blame culture caused the drivers to talk less openly about their driving behaviour and habits, because they were likely to be judged and punished for their 'crimes'. He claimed that because of this, drivers would likely tend to veil the real causes and factors that in fact led to the accidents, resulting in unreliable data about the accidents. As the following quote from his book clearly states, human beings should be trusted in their judgement to identify dangerous situations and dangerous segments as such and to react appropriately [Leeming, 1969, p.71]:

> „ It can safely be said that places which look dangerous do not have accidents, or very few. They happen at places which do not look dangerous. The reason for this is simple. The motorist is as intelligent as the 'local people'. If a place looks dangerous, he can see that it is, so he takes care and there are no accidents. He does not want to have an accident, and he will take care at obviously dangerous places. Accidents happen when there is some trap in road conditions which is not obvious at a glance, or where the conditions are too complicated for the limited human machine to deal with in the short time available. The driver has only a fraction of a second to size up a situation, and there may be some trap which he cannot see in this short time."

Taking all these arguments into consideration, one can certainly conclude that in order to determine to what extent the human factor affects traffic safety more precise, extensive and in-depth behavioural studies are necessary.

2.1.2 The Environmental Factor

Leeming [1969, p. 102] was convinced that casualties could be reduced using road-engineering methods, because the road and its surroundings can negatively affect traffic safety in several ways. For example by:

- not being self-explanatory. A self-explaining road is a road that supports the road users in their driving task, avoids unexpected and dangerous situations, and induces adequate behaviour. As knowledge about the relationship between single road design elements and their perception by the road user is limited, the design of such roads is not yet widely spread [Matena et al., 2008, p. 7].
- not being fault tolerant to the users' error. Fault tolerant roads try to minimize the severity of accidents. The most important element of fault tolerant roads are obstacle-free roadsides (i.e., free of poles, trees, etc.) and safety barriers around unremovable fixed objects, physical or wide-median lane separations, and mid- and side-barriers.
- not allowing the users to take compensating actions in case of errors and traffic conflicts. Safe roads should alert road users in case of dangerous behavior and give them space to take compensating actions, such as speeding down or braking. To keep road users on the lane, road markings as well as delineator posts should be reflective. Shoulder rumble strips and profiled lane edge markings should be installed in order to alert road users by producing noise and vibration if they begin to drive off the lane or road [Matena et al., 2008, p.10]. Further, the lane width should be determined in a way that the road users are provided with enough space at critical sections, such as curves.

These observations make it clear that a lot of thought about different design elements has to be put into the design of roads and that existing roads have to be analysed to identify safety deficiencies so that effective countermeasures can be elaborated. Common techniques to assess and evaluate roads with regard to their safety are described in Chapter 3.

2.1.3 The Vehicle Factor

The safety of vehicles used by road users represent the third important safety factor of the road traffic system and its relevance is highly accepted, as a vehicle's design highly affects the safety of its occupants and other road users in case of a collision. The industries are investing in vehicle safety tests in order to assess and evaluate the safety of their cars in order to make them more appealing to buyers than other vehicles. General Motors, for instance, performed the first barrier crash test as early as 1934. Several other companies followed and continuously incorporated vehicle design elements to increase the safety of the vehicle users in case of collisions.

The term used for a vehicle's ability to protect its occupants from death and severe injuries in case of an impact is called crashworthiness of a vehicle. When talking about the safety of a vehicle it is often the crashworthiness that is referred to.

To assess the crashworthiness of a vehicle several methods can be used. Computer simulations represent the cheapest form of vehicle safety assessment and do not require any collision to happen first. The most common and revealing form, however, are crash tests that are performed by the industries or independent groups who test vehicle prototypes for different collision scenarios to assess several safety criteria such as the deformation patterns of the vehicle structure, the acceleration of the vehicle during the impact, the level of injury as experienced by the used human body models, etc. The following types of crash tests exist:

- Frontal-Impact Tests: as the type of collision with the most severe effects, this type of tests are the most common type. They are carried out by driving a prototype into a solid concrete wall or by driving two prototypes into each other at specified speeds.
- Side-Impact Tests: represent an important type of tests as vehicles are often equipped with means to protect the occupants in the front seats in case of frontal impacts. Vehicles, by their structure, do not have a significant and sufficient crumple zone to absorb the impact forces.
- Roll-Over Tests: are performed to assess a vehicle's ability to protect its occupants in case of roll-overs.
- Offset Tests: are performed to assess the ability of only certain parts of a vehicle to absorb impact forces.

The European Car Assessment Programme (Euro NCAP)[1] is one of the major independent crash testers in Europe. Established in 1997 by road administrations in England and Sweden, it periodically publishes crash test results for different vehicle models. Euro NCAP tests the safety of occupants in frontal impacts at 64 km/h, side impacts at 50 km/h, and pole test at 29 km/h. The results of their subsets are then being considered together and are evaluated on a scale of maximum 37 points and 5 stars.

One often neglected aspect of vehicle safety is, however, the level of safety a vehicle can provide for road users other than its occupants, such as pedestrians.

[1] http://www.euroncap.com/

[2] http://www.erso.eu/safetynet/content/safetynet.htm

2.2 Improving Traffic Safety

The traffic system being a complex system with many factors, one can see that improvement mechanisms for traffic safety reflect this nature by addressing many factors at once. One popular approach is the „4E“ approach that suggests concentrating efforts on enforcement, education, engineering, and encouragement/economy [Martinez, 2000, p. 12].

However, the different approaches are categorized in the following subchapters in terms of the main traffic safety factor they address. First, the three factors are considered separately, giving an overview of approaches that address safety deficiencies of this specific factor alone. After that, approaches that address the road traffic system as a whole are analyzed.

2.2.1 Improvement Approaches Addressing the Human Factor

In a road traffic system, the human factor is the most complicated factor to address as it represents a complex system in itself. On the outward level, for instance, the driving skills of a road user could be improved by advanced driving courses or, while on the inward, most complex level, the general attitude of the road user towards safe driving has to be addressed in order to change the user's behaviour in traffic.

Four practical approaches to change road user behaviour are legislation, enforcement, reinforcement, and education. In the following these approaches are discussed in a little more detail.

Legislation. Legislation can be considered as the basic mechanism to change road user behaviour by setting socially acceptable standards (*declarative effect*) and by imposing sanctions on violators (*deterrent effect*) [Lonero and Clinton, 1998]. Examples for common legislation are seat belt legislation, child restraint legislation, motorcycle helmet legislation, and so forth. It is obvious that this mechanism relies heavily on education and enforcement.

[Lonero and Clinton, 1998] suggest the following guidelines in introducing new legislation:

- Communicate clearly to the public and the media about the reasons for, and the benefits expected from the legislation. Do not assume that people understand the reason(s) for it.
- Continue to improve the influence and deterrence of legislation by explicit planning, implementation and evaluation. Complacency leads to deterioration in effect.
- Improve deterrent effects with supporting initiatives in enforcement and publicity developed after analysis of the target populations and their current behaviour.

- Support individual values and controls related to health issues and the social costs of careless or irresponsible road use behaviours.
- Look beyond short-term effectiveness of new legislation with careful deliberate interventions designed to maintain positive behaviours and an optimal mix of effective supporting initiatives
- Help develop social norms favoring safe road use that will build on people's self-regulating processes.

Enforcement. Enforcement comprises preventing sanctions when laws are violated. It is interesting to note how differently road users can perceive sanctions: as a cost of doing business, as a moral issue, as an inefficient and discriminatory system, or even as a revenue generator for government [Lonero and Clinton, 1998].

Rothenatter [1992] analysed to which extent road users are influenced by traffic law enforcement and identified three kinds of effects of law enforcement on driver behaviour:

- On-view effect: can be observed when a driver becomes aware of police surveillance or other kinds of visible automatic policing systems. This effect can impact the road user's speed, lane choice, overtaking, and obeying traffic lights, etc. The effect lasts over narrow ranges of time and distance.

  [Lamm and Kloeckner, 1984] conducted a long-term study of 10 years for a motorway section in Germany and analysed the effect of the installation of photo radars and observerd that the number of fatal crashes was reduced from seven to one, and that the effects were maintained over the whole period of the study.
- Memory effect: can be observed when a driver travels the same stretch of roadway. The effect may last for as long as two weeks;
- Distance halo effect: is the halo effect when enforcement influences road user behavior over a wide geographic area.

The conclusions of Shinar and McKnight's extensive review [1985] of enforcement effects targeting speeding and DWI can be considered as guidelines in introducing new enforcement mechanisms:

- Enforcement units must be highly visible to be effective
- Visible enforcement must appear to be a real threat
- Enforcement efforts must be publicized

Reinforcement. Reinforcement techniques focus on motivating desirable behaviour rather than on discouraging wrong behaviour. This idea is cultivated from the point of view that crashes can be seen as results of desirable actions the road users missed to take, as opposed to the point of view where the crashes are considered to be results of the wrong actions road users take [Lonero and Clinton, 1998].

Here, incentives are being offered to motivate desirable actions, as it was done in the first systematic evaluation of incentives in road safety by Harano and Hubert [1974], for which road users who caused crashes or committed violations in the previous year were informed, that their licences would be extended free of charge for one year if they maintained a clean record in the forthcoming year. It turned out that young drivers and drivers whose licence renewal was due in the next year were affected the most.

Lonero and Clinton [1998] suggest the following guidelines for future work in this field:

- Use behavior-analysis techniques in operational programs to identify target behaviors and influence them.
- Develop practical incentives and feedback programs with appropriate evaluations to maintain their effectiveness.
- Encourage road users to develop internal controls, such as a wellness approach to their entire lifestyle and social responsibility.

Education. Education techniques to change road user behaviour focus on the skills a road user must develop, which are difficult to identify as empirical knowledge about required road skills is lacking [Lonero and Clinton, 1998]. Additionally there is the problem that different kinds of road users have to have different skills, so it is impossible to talk about a standardised set of skills that can be addressed by education techniques.

For children and teens, school-based programmes are being developed, which focus on motivating the use of bicycle helmets, seat belts, on safe road crossing for younger children, and on general driver education and responsible use of alcohol for teens. However, the short and long term effects of such programmes are not known empirically, because studies are mostly not systematically carried out and only few of them have been evaluated.

Other education programmes focus on adults or certain risk groups and try to increase awareness by means of campaigns broadcasted by the mass media and offensive billboards along the roads.

Lonero and Clinton [1984] suggest the following guidelines on developing new education programmes:

- Try to create more than short-term knowledge gains.
- Make sure media expenses are cost effective.
- Target children for complete road user skills.
- Integrate education into broader-based programming that uses a variety of methods such as social action, support for legislation and enforcement, incentives and publicity campaigns.
- Support community awareness of road safety and the development of local standards of behaviour.
- Support the development of a more constructive role for the news media.
- Redesign driver education to recognise the protracted process of learning to drive and the need to use driver education in conjunction with other motivational influences.

However it is important to state that to 'optimise' the user only is not going to be a general solution for road traffic safety problems, because the other factors cannot be neglected. For instance, special kinds of training increase the confidence of the driver, so much so that they see themselves as competent enough to handle dangerous situations and try less to avoid those.

2.2.2 Addressing the Environmental Factor

As already mentioned that road design elements affect road safety immensely. Even if all road users would follow all rules in traffic, a significant amount of fatalities would still remain. Therefore, roads have to be designed in a way to ensure that users have the room and time to take error compensating or alleviating actions to avoid a crash, or that they are not exposed to impact forces that can kill or severely injure them in case of a crash [Delaney et al., 2003].

In this subsection a list of promising road design developments are listed and explained. The first three subsections contain measures that address general road design elements, whereas the last subsection is about improving the safety at road intersections.

Road Side Safety Barriers. High speed collisions with fixed roadside hazards, such as trees, poles, barriers, etc., account for almost 40-50% of all fatalities and serious injuries in Australia, 25-30% in the USA, and 25% in Sweden. The tolerable impact speed here may be as low as 30 km/h, because higher speed collisions may result in high-level intrusion of hazards into passenger compartments even with modern vehicles with several safety features [Delaney et al., 2003].

Key strategies to address such roadside hazards can be listed as follows in decreasing order of their implementing costs [Delaney et al., 2003, p. 4]:

- Development of clear zones: Clear zones are areas of land immediately adjacent to the road that have been freed of unprotected hazards to allow errant users to stop or slow down without a fatal or severe collision.
- Modifying roadside hazards to totally avoid or reduce consequences of collisions
- Installing warning elements such as shoulder rumble strips to alert drivers that they are drifting off the road.
- Reducing impact speeds.

Median Safety Barriers. One of the most severe crash types is head-on crashes, which happen mostly in rural areas on undivided roads. As it is unlikely that all narrow roads are going to be extended and divided, there is a need for flexible median safety barriers that can be implemented without too much cost.

One low-cost approach that has been thoroughly tested in Sweden is the **2+1 Concept** (see Figure 2-1) with wire ropes as flexible median safety barriers. For this approach, a third lane is introduced on 13 m roads, with the middle lane changing direction every 2.5 to 3.5 km. The results showed that, even though collisions with the barriers causing only limited injuries were frequent, the number of fatalities decreased by up to 76% [Larsson et al., 2003].

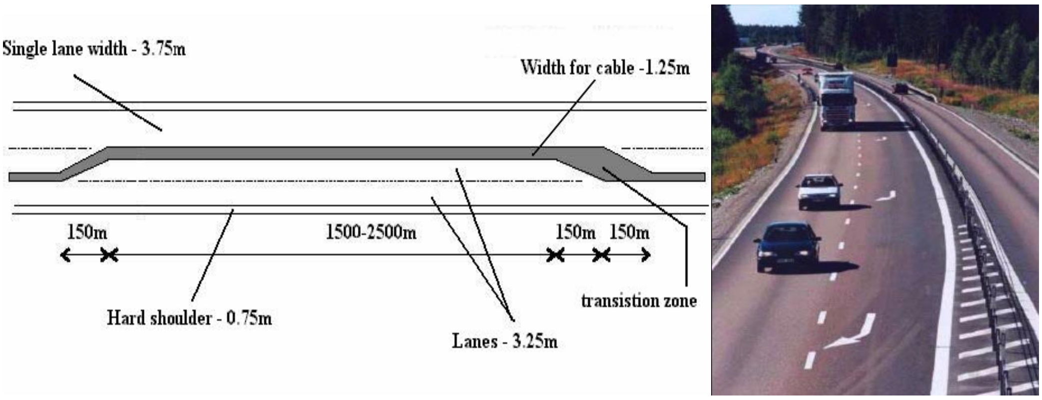

Figure 2-1: 2+1 road in Sweden (left) and its concept details (right) [[Larsson et al., 2003]]

The general expected reductions in accident rates are [Nilsson and Prior, 2004, p. 5]:

- 35-50% reduction in the number of fatalities
- 30-45% reduction in the number of fatalities and severely injured
- No increase or slight increase in the number of mild injuries
- 30% increase in the number of non-injury accidents

Road Surface Markings. Markings on road surfaces that convey either guidance or information to road users (i.e., drivers and pedestrians) are one of the most important road design elements as they often represent the only continuous means of guidance during their travels, especially longitudinal pavement markings to delineate lanes or to signalise sleeping drivers when they drift off the road [Carnaby, 2004]. The general goal of road surface markings is to provide guidance in a for drivers mentally and physically undemanding fashion. Efforts to improve the marking system lead to several developments that increase the night time visibility and longevity of the markings.

Night time visibility of pavement markings is defined as the retro reflectivity of the markings, that is the efficiency of the marking to reflect light in the direction it came from. This measure highly depends on the paint that is used and the glass beads the paint contains [Carnaby, 2004]. The absolute minimum is considered to be 100 mcd/lux/m^2 (see first line in Figure 2-1).

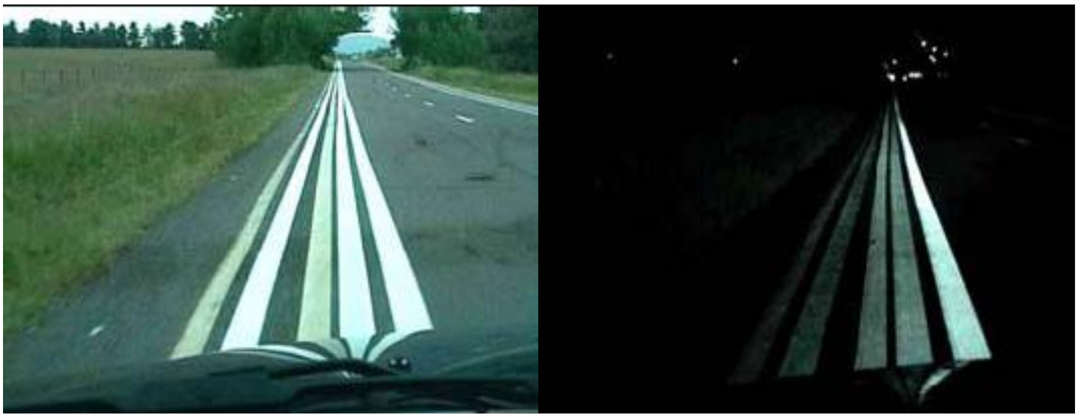

Figure 2-2: Road surface markings with different values of night time visibility [Carnaby, 2004, p. 2].

Another attempt to increase road traffic safety by using road surface elements are perceptual countermeasures against excessive speeding, where the driver is presented a manipulated road scene to influence his driving behaviour [Macaulay et al., 2002]. One of their main advantages is their relatively low installation costs. One example for such a countermeasure are patterns painted on the road surface that induce the illusion that the driver is travelling much faster than they actually do.

Improving Road Safety at Road Intersections. Road intersections, that is, segments within the road network where the paths of road users cross, are responsible for many crashes as they often increase the probability of conflict by increasing the complexity of the driving situation.

In this subsection we are going to look at several improvement measures to improve road safety at intersections as listed and described in [Corben et al., 2005, p. 4-6]:

- Treatments to reduce speed are one of the most common ways to address crashes at intersections and is done through pavement narrowing, alteration of the road surface (particularly raising of the surface), and enhancing speed limit compliances.
- Provision of grade-separated intersections, are one of the high-cost measures and therefore generally considered for high-volume roads, such as freeways, highways, and dual carriageways. Such intersections remove the major points of conflict and are considered to greatly enhance safety.
- Roundabouts as safe traffic control devices are popular, because they reduce the crash and injury risk through simplified conflicts, reduced speed, and less dangerous collision angles.
- Provision of adequate sight distance, delineation, and alignment at intersections to reduce collisions and their severity, especially at intersection entries and turnings, have been shown as effective measures.
- Provision of warning signs is another measure to increase road traffic safety to call the attention of the driver to hazardous conditions that may not be apparent at first sight. Popular warning signs are flashing bacons, variable message signs, and vehicle activated signs.

However, it is important to state that to improve the roads alone cannot improve the roads safety in general, because the other factors will still play their role within the system. It has been observed that when drivers think of a road as safe, they tend to act more carelessly, whereas if a road is in a bad condition, they tend to be more careful and choose to drive at a lower speed or drive more alert. So much so that on some roads several “improvements” had to be reversed [Hoyos et al., 1995].

2.2.3 Addressing the Vehicle Factor

Utilising the results of several kinds of crash tests and available accident data the industry invests in the installation of safety equipment in vehicles, even though at different levels. The reason that not all vehicles have the same safety equipment is that not all drivers are ready to pay for the additional costs. Therefore we can observe that manufacturers often incorporate only the mandatory equipment by default and provide the rest optionally.

Mandatory safety equipment differs from country to country. The provision of turn and brake lights, of mirrors to eliminate black spots, and of seat belts for the front seats, however, seems to be mandatory in every country. Other kinds of equipment are not mandatory but more and more demanded by the buyers. They can be categorised as equipment for active safety and for passive safety. Active safety equipment focus on increasing the overall road safety by preventing collisions, whereas passive safety equipment focus on increasing the vehicle's occupants safety by reducing the effects of collisions. Common active safety equipment includes the following:

- Anti-lock Braking System (ABS) aims to prevent the wheels from locking under heavy braking allowing the driver to maintain steering control.
- Electronic Controls: Some of them control the speed of a vehicle to prevent it from exceeding certain speed limits. Others use several sensors to detect if the driver looses control over the vehicle, and intervene by reducing the speed or by applying the brakes.
- Warning signals: are visual or audio signals to warn the driver in case

Common passive safety equipment includes the following:

- Child protection: As vehicles and standard safety equipment are designed for normal sized adults, children are more exposed to dangers. Regular seat belts, for instance, are not suitable for a child's safety as it could do more harm than good in case of a collision. Besides legal regulations that command that children below the age of 12 or the weight of 40 kg have to sit in the back seat, there are several features that vehicle manufacturers offer such as child locks to prevent children from accidentally opening the doors from inside, booster seats to put the child in a position in which the vehicle's seat belts can actually be used for protection.
- Crumple zones: are incorporated in the structure of vehicles to absorb the energy of a collision in order to prevent them from affecting the passenger compartment of the vehicle.
- Airbags: are rapidly inflating envelopes for cushioning against the hard interior parts of a vehicle and is triggered by the rapid deceleration of the vehicle.
- Energy absorbing materials: are used at certain parts of the vehicle to decrease the affects in case of an impact with an occupant. Most common examples are padding the dashboard, or using deformable material for the windshields.

As the role of vehicle design and material for pedestrian safety in car-pedestrian collisions became obvious, improvements have been made to enhance vehicle design so that pedestrians are affected to a minimum. The most common regulation for that purpose is the determined minimum and maximum height of the vehicle's bonnet. The developments focus on protecting mainly the head and then the limbs of pedestrians. A certain amount of space between the hood and the underlying engine would be enough to absorb the energy and prevent the pedestrian's death. However, because of certain design constraints, it is not always easy to provide such a space. Another way is to use deformable and / or absorbing materials at the main impact points [Crandall et al., 2002].

Another preventive method regulated by the legislation is the mandatory inspection of vehicles in certain periods. In doing so it can be ensured that vehicles on the roads are adhering to certain safety standards.

However, it is important to state that to optimise the vehicles' safety alone cannot be the solution to traffic safety problems either. The more a vehicle is improved technically and endorsed as “secure”, conveying the message that the occupants are safe in case of accidents, drivers tend to drive again more carelessly [Hoyos et al., 1995]. Drivers of vehicles that are equipped with an ABS system for instance, tend to drive at higher speeds.

2.2.4 Initiatives Addressing Road Traffic Safety

Since the importance of road traffic safety has been recognised, many research groups are working on approaches to increase safety by addressing the factors that affect safety. Some of them focus on single factors, while others consider the interactions between the factors and provide a more holistic approach. In this subsection several important approaches and studies are listed to explain which factors they address and how.

Vision Zero. The Swedish Vision Zero project started in 1995 and presented a whole new view on road safety problems as it introduced an ethical approach by stating that road deaths are unacceptable and that their vision of the future was one in which no one will be killed or seriously injured on roads. It emphasised that it is necessary to consider the road traffic system as a whole in which roads, vehicles, and road users must interact in order to ensure safety.

Vision Zero altered the view on responsibility by introducing the idea of shared responsibility in which the road designer, road manager, vehicle manufacturer, road transport carrier, politicians, public employees, legislative authorities, and the police is responsible for road safety as much as the individual person who is responsible to abide the laws and regulations [Baker et al., 1974].

Within the project it was recognised that it is not realistic to think that road users will not make any mistakes, they will. However, these mistakes should not be punished by death. This point of view leads to the project's objective to prevent crashes on the one hand, but at the same time to design the road system in a way that the effects of the mistakes do not lead to serious injuries or deaths [Baker et al., 1974].

According to the Swedish Road Administration, the implementation of the Vision Zero project resulted in safer road environments, which have been achieved by [Baker et al., 1974, p. 10]Baker et al., 1974:

- more roundabouts as means to simplify conflicts, reduce impact speeds, and ensure more favourable collision angles
- the implementation of 2+1 lane concept with a median barrier (see Section 2.2.2)
- establishing lower speed limits in built-up areas
- ensuring safer roadsides cleared of dangerous objects such as trees and boulders to minimise the damage ensuing from cars veering off the road.

SafetyNet. The SafetyNet[2] project is an integrated project funded by the Directorate - General Energy and Transport (DG-TREN) of the European Commission, bringing together 22 institutes from 17 countries. The objective of the project is to build the framework of a European Road Safety Observatory, as primary focus for road safety data and knowledge by extending the CARE database and by developing new fatal and in-depth accident causation databases. One objective of the observatory is also to develop new statistical methods to analyse the combined data.

RIPCORD iSEREST. The RIPCORD iSEREST[3] project focuses on collecting and evaluating existing approaches to road safety in order to make them accessible throughout Europe. The project has brought together 17 partners from 14 nations including scientific institutions, road authorities, and industrial companies. The project officially started in 2005 and was to continue for three years. The specific goals of the project has been to develop best practice guidelines for:

- Road Safety Impact Assessment tools and Accident Prediction Models
- Road Design and Road Environment
- Road Safety Audit

[2] http://www.erso.eu/safetynet/content/safetynet.htm
[3] http://ripcord.bast.de/

- Road Safety Inspection
- Black Spot Management and Safety Analysis of Road Network

SUPREME. The SUPREME project focuses on collecting, analyzing, and publishing best practices in road safety in the European Union in order to facilitate their implementation in as many member states as possible. For that purpose, practices from nine categories of road safety are considered [Supreme, 2007, p. 6]:

- Institutional organization of road safety
- Road infrastructure
- Vehicles and safety devices
- Road safety education and campaigns
- Driver training
- Traffic law enforcement
- Rehabilitation and diagnostics
- Post accident care
- Road safety data and data collection

Practices from these categories are analyzed with regard to characteristics such as target groups, goals, key issues, duration and process of implementation, duration of effects, coverage, costs, success factors, and potential implementation barriers in other member states. The main task after these analyses is to identify the best practice among the vast amount of explored practices. For that purpose, existing practices are rated as best, good, and promising practice. To gain the best practice status, a measure should lead to a significant reduction of road crashes, deaths, and serious injuries; should offer a positive cost-benefit ratio, sustainability, and good public acceptance [Supreme, 2007]. A questionnaire about the gathered information was sent to experts along with the mentioned rating scheme. The results were summoned and resulted in their published handbook that include a list of measures at European level [Supreme, 2007] and states several best practice measures in the category of policy framework for efficient road safety, which include, among others, the Swedish Vision Zero project and the Dutch Sustainable Safety project. It also states several best practice measures in the category vehicle safety, which include, among others, the EuroNCAP project and the daytime running light measure. For a more extensive list of the identified best, good, and promising practice measures in the other categories, the interested reader is referred to the handbook itself.

All these projects show that safety improvement can be achieved by addressing different factors of the road traffic system. However, latest reports indicate that in leading developed countries, investing in safer infrastructures is expected to deliver twice the casualty saving provided by investing in either behaviour or vehicles [iRAP, 2008, p. 5]. Therefore it is essential to assess the current state of the roads and their surroundings in terms of their safety, which is the main focus in the next chapter.

CHAPTER 3

3 Road Safety Assessment

When talking about road traffic systems it is referring to a complex system of many interacting elements for which it is not explicitly and definitely specified what factors contribute to what extent to the safety or 'unsafety' of it (some of the factors and their possible impacts are discussed in Section 2.1). Early initiatives to improve road traffic safety, concentrated on improving the driver through education, training, and enforcement. However, Leeming [1969] was convinced that drivers were not the main cause of road safety problems and argued that road casualties could be reduced by using road-engineering methods. In more recent work, one can observe that the focus is on protecting road users by putting more effort into the design of vehicles and roads, the latter being the focus of this thesis.

It seems impossible to develop a theoretically correct and complete assessment model that covers all safety aspects related to the design and infrastructure of roads. However, there are several techniques that emerged and evolved over the years through experience and empirical data.

The most available kind of data related to road safety is accident data. Two of the most important methods that use accident data to assess the safety of a certain section or spot on a road are the *Black Spot Management* (BSM) and the relatively new *Network Safety Management* (NSM), which are also referred to as reactive methods. BSM focuses on the identification, analysis, and treatment of black spots, which are locations that have a higher expected number of accidents than other locations, because of local risk factors. NSM focuses on the identification, analysis, and treatment of hazardous road sections, which have a higher number and severity of accidents than other similar road sections, due to section based accident and injury factors [Sørensen, 2007, p. 33]. NSM differs from BSM by focusing on longer road sections of 2-10 kilometres, whereas black spots are seldom longer than 0.5 kilometres [Cardoso et al., 2007, p. 5].

The main disadvantage of reactive methods is that accidents have to happen first, before dangerous sections can be identified and the safety can be improved. Besides, to achieve a significant cut in road casualties in the short, medium, and long term, it is necessary to address the whole road network, rather than a few black spots that might have high short-term crash records [iRAP, 2008, p. 7].

Preventive methods, as opposed to the reactive ones, try to overcome this disadvantage by trying to detect hazards on the roads and fix them, before accidents happen. The *Traffic Conflict Technique* (TCT) and the *Road Safety Inspection* (RSI) method from this category will be examined. The TCT concentrates on surveying traffic conflicts to determine their causes and to work on solutions to eliminate them. The most important advantage of the TCT is that, compared to accident data, traffic conflict data can be gathered within a shorter period of time [Chin and Quek, 1997, p. 2]. RSIs concentrate on surveying several pre-defined construction and design elements on the roads, reporting the deviations from the stated standards, suggesting improvement measures and monitoring their implementation. Such preventive methods also enable the evaluation of new roads and safety programs. At this point it is important to state that these methods should be considered as complementary methods rather than alternatives.

An example for a project that combines derivatives of NSM and RSI is the European Road Safety Assessment Programme (EuroRAP), which concentrates on identifying risk distributions across major roads to define priorities for assessment.

In the following section main limitations to the usage of accident data are pointed out that should be taken into account before studying the reactive methods of BSM and NSM, which are discussed in the subsequent two sections. Then a closer look at the two preventive methods, TCT and RSI is taken. The chapter is closed with a detailed study of the European Road Safety Assessment Programme which represents the state of the art assessment method that is used in many countries around the globe.

3.1 Limitations to the Usage of Accident Data

Many methods for road safety assessment, such as the two methods described in the Sections 3.2.1 and 3.2.2, use accident data, because the safety or unsafety of a road is often being judged based on the number of crashes that occur on it and the major indicators for the existence of safety deficiencies on roads are considered to be the occurrence and severity of crashes.

Even though accident data can prove to be useful in many instances, there are nonetheless several serious limitations to their usage that should not be forgotten.

Low rate occurrence or no accident data at all. Even though the number of fatalities from road accidents, compared to other causes of death, is still unacceptably high, accident frequencies segregated by location, time, and type are generally low. Therefore, it is not easy to derive statistically significant results from accident data by merely examining the accident counts [Chin and Quek, 1997, p. 2].

An important question arises when trying to determine how safe new build roads are, for which no accident data exists yet. It is also hard to classify roads on which only one but severe accident occurred once over a long period, but severe traffic conflicts take place much more often. Would it be correct to classify such roads as safe? Another problem arises when the actual point of the road where the accident happens does not help to identify the 'unsafe' section of the road. The hazard itself might be present along the whole road, yet the accident happens at any point along it. Would it be correct to say that the road is safer than the actual point of the accident?

Irregular and incomplete accident reports. Besides the above mentioned issues, there is also the problem that detailed and uniform data on accidents is not always available, either because the police or judicial system do not systematically produce investigation reports for every accident for a number of practical reasons (e.g., shortage of manpower, seeing no point in recording the details of an accident unlikely to go to court, etc.) or because existing reports are not classified and are therefore difficult to access [Muhlrad, 1993, p. 6].
In Chapter 2 was mentioned that the traffic system comprises of several elements, which affect the road safety in different ways. Therefore, in most cases, the occurrence of an accident cannot be related to only one factor or cause. It is rather an outcome of a complex process of interaction involving the road traffic system's elements: the driver, his vehicle, and the road environment. Therefore, it is sometimes difficult to pinpoint the main causes of accidents just by examining accident counts alone. One rather should be primarily interested in the question of which problematic behaviour or interaction between the road traffic system’s elements led to the accident Risser et al., 1991].

Problems like these suggest that it should be considered to what extent accident data could reliably predict the safety level of a road.

3.2 Reactive Methods

3.2.1 Black Spot Management

Black Spot Management (BSM) has been for several years the essential part of site-specific traffic safety work. However, the quality and approaches of BSM show significant differences from country to country, characterised by a lack of standardised definitions and methods. In this section is described how BSM is defined and implemented according to the best practice guidelines by Sørensen [2007, p. 106].

The so called **black spots** in BSM, can be defined as road sections that have been accounted as being particularly accident-prone. To identify and analyse spots like these is the focus of BSM projects and their overall workflow can be summarised in the following three steps:

1. Dividing the road network into different road elements and sections
2. Identifying and ranking of black spots
3. Analysing black spots and evaluating black spot treatment

Dividing the Road Network

In order to identify and analyse black spots, it is necessary to divide the road network in smaller sections for which it is possible to estimate the expected number of accidents based on available accident data. Here, the use of clearly defined road elements, such as sections of a specified length, curves with radius within a certain range, bridges, tunnels, etc., is more preferable than the use of roughly defined sliding windows. This approach is less resource demanding and easier to understand than the approach with sliding windows.

However, this segmentation approach has the drawback that it is possible that the obtained segments do not match the accident pattern in cases where accident peaks are divided into two adjacent segments and are therefore overseen. Further, with too short segments, there is also the risk of wrongly identifying random accident peaks as black spots. These are most probably the reasons why countries like Austria, Denmark, Norway, and Portugal prefer the sliding window approach instead.

Identification and Ranking of Black Spots

BSM identifies black spots using accident-based methods, which can be divided into three groups: not model based, model based, and accident specific methods.

Not model based methods represent the easiest way for detecting black spots, as they work without road and traffic data and can be implemented by local or regional authorities by using the following parameters:

- Absolute number of accidents
- Frequency: accidents per kilometre
- Rate: accidents per vehicle kilometre
- Frequency-rate
- Combinations of the previous parameters

Besides the disadvantage of these simple methods of depending highly on incomplete and imprecise accident data, the most important disadvantage is that the systematic variation is not taken into account, leading to the identification of road elements that are generally unsafe, rather than local risky black spots. Another problem is that, as an effect of random fluctuations, normal road elements with a high number of accidents can be wrongly identified as black spots (*false positives*) or black spots are overseen because of randomly low number of accidents (*false negatives*).

Model based methods are considered the best methods from a theoretical point of view, because other than not model based methods, the systematic variation and the stochastic nature of accidents are taken into account here and the general road design is also considered. However, they are much more complex and require comprehensive and connected accident, road, and traffic data and hence, are difficult to understand and implement.

Accident specific methods use only a subset of the available accident data. Criteria like weighted injuries or specific accident types can be used to define the subsets. The reduction of the amount of the used data has two effects. The positive one is that interference from non-site specific accidents is removed. The negative one is that reducing the amount of data, which is often already limited, can cause problems of missing to identify existing deficiencies.

Even though it was attempted to develop several not accident based methods to identify black spots, they have not become an integrated part of BSM, mainly because such they are difficult to develop and implement. Because of that BSM is classified as an accident based method and hence, considered under the class of reactive methods.

Analyzing Black Spots

The goal of this step is to analyse the identified sections in order to ascertain, if they are really black spots and if so, to figure out why they have became black spots. The analysis has to result in the identification of the accident factors (i.e., why the accidents happened) and of the injury factors (i.e., why the accidents led to injuries) [Sørensen and Elvik, 2005, p. 41].

Several methods to analyse black spots exist, but they can be considered mainly in two categories: office analyses and field analyses with focus on accidents, the road and its surroundings, the traffic, or a combination of these (see Table 3-1).

	Office analyses	**Field analyses**
Accident	- General/statistical accident analyses - Specific/detailed accident analysis - Collision diagram	-
Road	- Condition diagram - Curve analysis	- Inspection - Observation
Traffic	- Traffic analysis (e.g., speed)	- Traffic conflicts
Combination	- Blinded-math-pair-comparison (state-of-the-art)	-

Table 3-1: Site specific black spot analysis methods [**Sørensen, 2007**, p. 48]

General accident analysis is one of the most relevant methods to analyse black spots that statistically analyses accident data in order to recognise accident patterns. The underlying idea is that frequent accidents are often caused by the same problems, which will lead to similar accidents if nothing is done to eliminate the safety hazards. According to the report of best practice guidelines for BSM, Sørensen recommends the following circumstances to be included in a general accident analysis [Sørensen, 2007, p. 49]:

- **Recorded accidents:** Number of accidents distributed according to personal injury and property damage, as well as personal injury distributed according to persons killed, seriously injured, and persons with minor injuries.
- **Variation over time:** Accident distribution during the day, week, year, and accident period.
- **Type of accident:** Accident distribution on situation and combination of parties involved.
- **Site:** Accident distribution on by roadside development, layout of road, and speed limit.

- **Circumstances:** Accident distribution by weather, lighting conditions, visibility, illumination, state of the roads, accident in school zones, road works, accidents due to drunk driving, obstacles on or outside the roadway and speed estimate.
- **Means of transport:** Accident distribution by element and vehicle.
- **Characterization of persons:** Accident distribution by blood alcohol content, gender, age, nationality, illness and use of safety equipment and parties involved.

Collision diagrams are also one of the most relevant methods for analysing black spots as they display all registered accidents with their different parameters. They give a good overview of the site to understand frequent and over-represented accidents (see Figure 3-1). However, to draw these diagrams are time consuming and resource demanding as they are normally drawn by hand. Even though there are some efforts to provide computer-based means to draw collision diagrams[4], but some analysts argue that the drawing itself is an important part of the analysis.

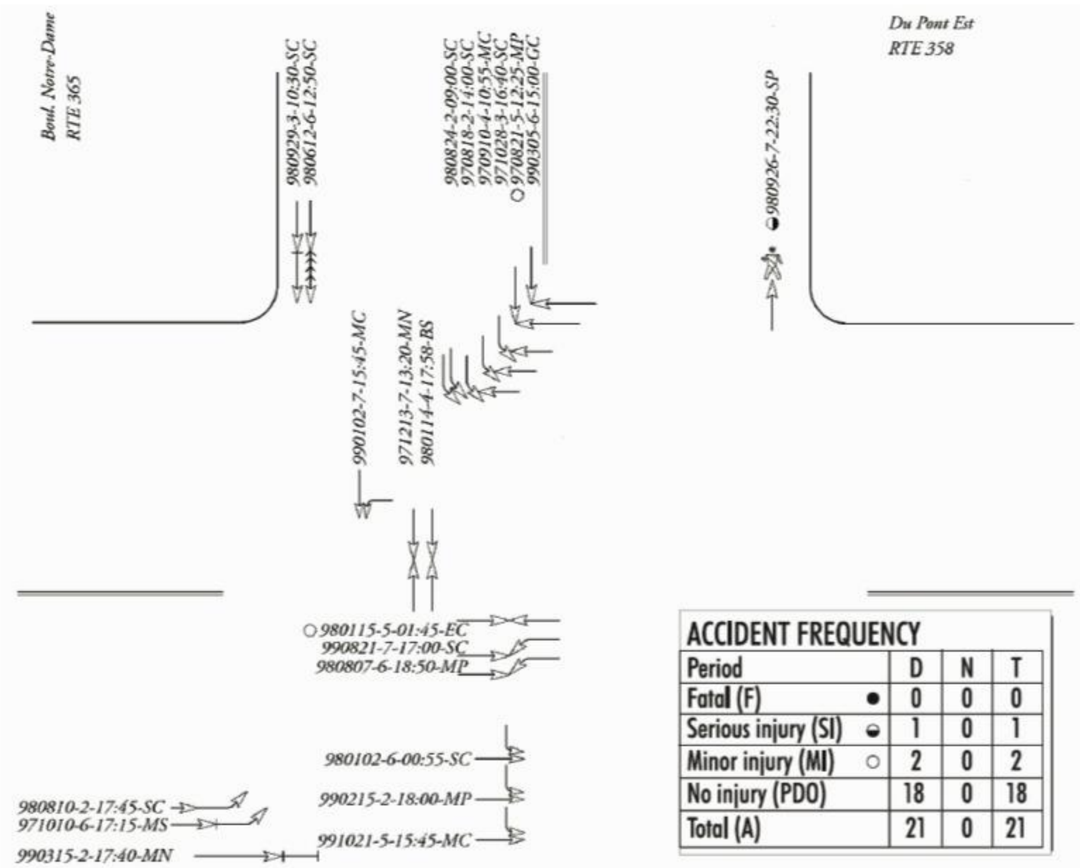

Figure 3-1: Example of a collision diagramm **[Sørensen, 2007, p. 50]**

[4] http://www.safetyanalyst.org

Field analyses, such as on-site inspections and traffic conflict studies are powerful methods to analyse hazards on the road, because they help to confirm the results of office side analyses and to understand the reasons behind hazards. They can also be used to detect unidentified problems that were not represented in the accident data. Due to the limited resources of local authorities and the fact that field analysis are very expensive, a balance has to be achieved between a detailed analysis to identify all risk factors and the arising costs.

Having identified and analysed black spots, the next step would be to suggest appropriate treatment and to monitor and evaluate their effects after implementation. But this part is not relevant for this thesis.

3.2.2 Network Safety Management

More recently, a supplemented version of Black Spot Management (BSM) with safety analysis of road networks has been developed, which is called Network Safety Management (NSM) [Sørensen, 2007] and is actively being used since 2005 on motorways and two-laned rural roads. It seems that most of the work in that direction has been done in France and Germany [BASt and Sétra, 2005].

The workflow of NSM projects is similar to the workflow of BSM projects and can be summarised in the following three steps, which are described in this section.

1. Dividing the road network into sections
2. Network-wide statistical analysis of accident data
3. Analysis of worst performing sections and priority ranking of measures

To analyse the roads and to select sections for further analysis, NSM utilises available accident data and also integrates accident severity [Sørensen, 2007] completely and systematically at the identification stage. Because each country has different definitions for terms to describe accidents and accident severities, NSM submits to three categories of accidents, so that data from each country can be adapted to fit these categories [BASt and Sétra, 2005, p. 75]:

- SI: Several personal injury accident (fatalities and serious injuries)
- MI: Minor personal injury accident
- SD: Severe material damage-only accident

A further distinction can be made between accidents with fatalities and accidents with serious injuries. Even though the results of the analyses highly depend on the quality and amount of available data, lack of information of category SD is bearable. Another important aspect that has to be considered at this stage is the timeliness of the available data. NSM, therefore, declares a period of three to five years for which accident data is considered accurate.

Dividing the Road Network

In order to identify and analyse hazardous road sections, the road network has to be divided into sections, where it is important that the sections are as homogenous as possible to ensure informative and comparable results [Sørensen, 2007]. There are two ways to divide the road network into sections [BASt and Sétra, 2005, p. 7]:

- Dividing the road based on the network structure
- Dividing the road based on accident occurrence

When dividing the road system based on the network structure, the sections should be around 10 km long (minimum of 3 km) and have to be similar with regard to their traffic volume, cross section, and the type of environment. When dividing the road system based on accident occurrences, the sections should contain at least four accidents of the type SI. A visualisation of the accident distribution (i.e., accident map) could prove to be useful for the second approach.

Network-wide Statistical Analysis of Accident Data

The objective of network-wide statistical analysis is to identify hazardous road sections. In NSM these are defined as the sections with the largest safety potential. The safety potential is defined as the absolute difference between the registered and the general expected or average number of accidents. As such it indicates the obtainable reduction of accidents on a road section [Sørensen, 2007].

To compute the safety potential (SAPO) of a road section, the costs for accidents have to be given. Even though each country has its own way to determine these costs, it does not affect NSM, as long as the considered road sections are in the same country and the same cost values are used consistently. A mean cost per accident (MCA) has to be calculated for each accident category on each road type of the country. After that the sections can be rated using the formula below:

SAPO = ACD – bACD

, where ACD is defined as the accident cost density of the road section and bACD is defined as as the basic accident cost density of the road section and represents the anticipated average annual number of accidents and severity of road accidents.

Having formed a safety potential map (see Figure 3-2) of a road network, the sections with the highest SAPO values are then recommended (see Figure 3-3) for further analysis and treatment, as they indicate the road sections with a particularly high need for improvement and also with particularly high improvement potential [BASt and Sétra, 2005, p. 10].

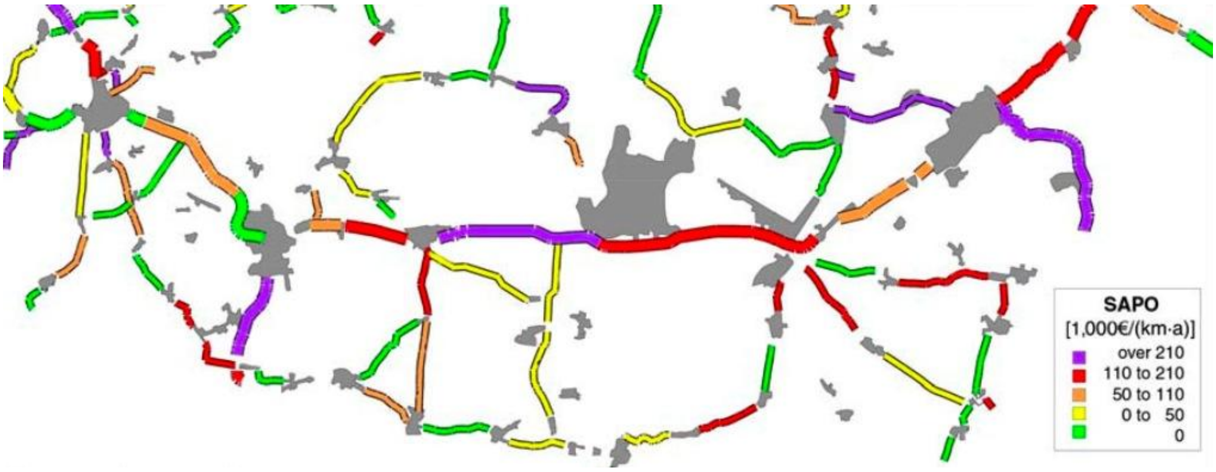

Figure 3-2: Map of road network showing the distribution of safety potential **[BASt and Sétra, 2005, p. 10]**

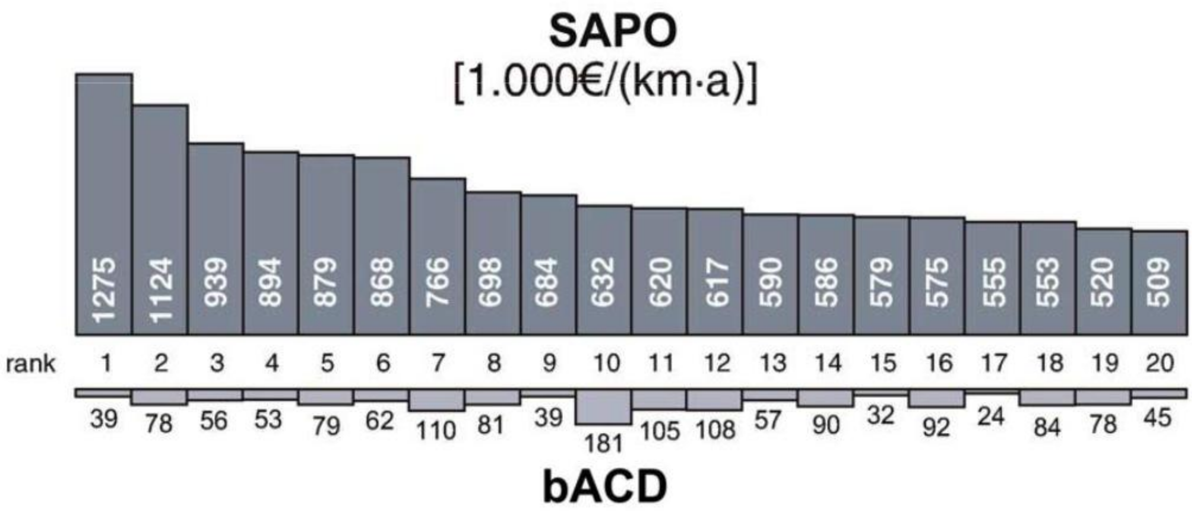

Figure 3-3: Chart of road sections with the highest safety potential **[BASt and Sétra, 2005, p. 10]**

Analysing Sections

The road sections, which have been identified as the ones with the highest safety potentials, are considered for further analysis at this stage to find and suggest appropriate treatment. The accident structure for these sections is inspected to determine conspicuous patterns. By comparing the percentage of present accidents on the analysed road section with the average percentage on this road type or the best practice value, such conspicuous patterns can be found. To make this possible, it is necessary, that the accident database provide enough information about the characteristics of the accidents.

Further, it is necessary to take more information about each accident like police reports into account, in order to decide to what extent the road structure has been involved in the accident. This is again a question, which cannot be answered clearly, but is important nevertheless. Because the objective is to understand the dysfunctions of the road to find the best countermeasures, we have to ask this question and take a point of view, where the road is prejudiced guilty.

3.3 Preventive Methods

3.3.1 Traffic Conflict Technique (TCT)

It was Perkins and Harris [1967] from the General Motors Corporation, who first formally stated the concept of traffic conflicts. They developed an observational procedure to test to what extent cars from General Motors were involved in unsafe traffic situations.

The Traffic Conflict Technique (TCT) today is essentially what became of that initial formally stated procedure. This technique focuses on the detection of traffic conflicts in real traffic situations that can be classified as "near-accidents" or "critical incidents" [Muhlrad, 1993, p. 6]. Specially trained people conduct the studies on the road and the gathered data is then analysed in order to determine the factors contributing to these unsafe situations and to elaborate solutions to prevent them. Because conflicts are considered as potential accidents, both being results of a breakdown of the interaction between the traffic system's elements and both requiring the same evasive actions such as braking and so forthHydén, 1987, it is supposed that the implementation of these solutions will also contribute to the prevention of accidents.

This technique immediately gained popularity, as it was considered as a complementary approach, if not a substitute, to existing traditional methods that relied on accident data. Since then many research groups worked on the development of TCT methods, which differ from one another to some extent, mainly in terms of their operational descriptions of traffic conflicts and their methods for conflict severity rating.

The following unified definition for a traffic conflict was proposed and agreed upon at the first Workshop on Traffic Conflict in 1977 [Amundsen and Hydén, 1977, p. 135]:

> “A traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remained unchanged”.

Even though this definition provides a common basis for working with traffic conflicts, it does not make a clear distinction between a conflict and a non-conflict situation in practice, allowing a wide latitude of interpretations and so giving rise to the problem of inconsistency in interpretation and ranking of various similar situations by the same observer (intra-rater variation) or of a given situation by different observers (inter-rater variation).

Many attempts have been made to achieve uniformity in interpretation using more detailed specifications of different groups of conflicts. In the first conflict study conducted by Perkins and Harris [1967], for instance, traffic conflicts were defined based on evasive actions taken by drivers. These evasive actions were related to easily recognisable activities, such as the appearance of brake lights or sudden changing of lanes, which could be easily identified and recorded by the observers. However, with this method the observers still have to rely on their intuition for determining whether an action was evasive in its nature or not.

To increase consistency by decreasing the subjective decisions that have to made by the observer, it was suggested to use measurable criteria to rate the severity of a traffic conflict, such as time and space proximity between vehicles. For the Swedish Conflict Technique [Hydén, 1987], for instance, an observer has to assess the distance and speed of vehicles and use the pre-defined threshold (see Figure 3-4) to distinguish between serious and non-serious conflicts. It should be noted that while the measure is quantitative, the measurement itself is still subjectively done.

Others argued that the cognition of an expert would be accurate enough to distinguish between severe and non-severe conflicts and that appropriate training can improve the observers to a degree that they can easily classify the severity of different situation sufficiently well. Accordingly, the methods used in Austria [Risser and Schützenhöfer, 1984], Germany [Erke and Gstalter, 1985], France [Muhlrad and Dupré, 1984], and the USA [Glauz and Migletz, 1984], do not use quantitative methods but define severity levels semantically, such as „was not so dangerous“, „was very close“, „collision averted by an inch“, etc.

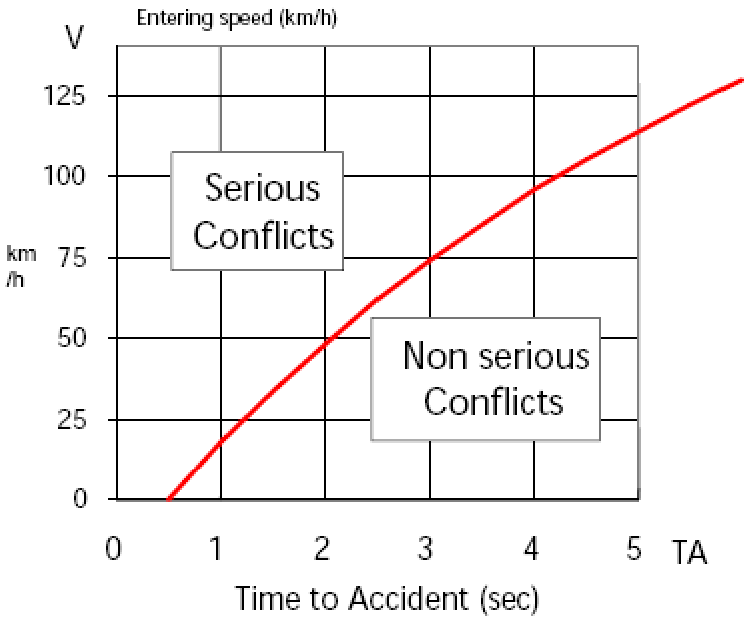

Figure 3-4: Function of the threshold between serious and non-serious conflicts [**Dao et al., 2005**, pp8]

In any case, it is important that the observers are well-trained so that they can differentiate between conflict and non-conflict situations and classify the severity of conflicts as consistently as possible. However, comparative studies showed that even if the conflicts are well-defined and the observers well-trained, there can still be significant variations in observation, especially when it comes to the less serious conflicts. This circumstance caused scepticism about the validity of the TCT to indicate the safety potential of the road, as the observations are difficult to verify [Chin and Quek, 1997, p. 8].

TCT methods are applied either to analyze the factors that contribute to unsafe situations and accidents on certain spots or segments on the road, or to analyze the effects of certain road design elements on traffic safety, such as the influence of traffic signals [Sayed, 1997] and their timing [Retting and Greene, 1997] at intersections.

The validity and the relevance of this method should be acknowledged within the Road Traffic Safety community, as it has been within other safety related areas, such as air travel, where the relevance of analyzing critical incidents to support preventive actions is taken for granted [Muhlrad, 1993].

3.3.2 Road Safety Inspection

The main objective of Road Safety Inspections (RSIs) is to monitor existing roads on a regular basis, to identify traffic hazards related to the road environment characteristics, and to propose interventions to mitigate the detected hazards, thus raising the safety level of existing roads. RSI should not be confused with the Road Safety Audit (RSA) to test the design of new roads or the reconstruction of existing roads.

RSI is considered as a preventive tool, because neither its initiation nor its implementation depends on any kind of accident data or knowledge about the safety level of the relevant road. Only general knowledge on road hazards, safety issues related to the road environment, and effective infrastructure interventions are needed.

Nevertheless, in some EU countries accident data is used either to decide which roads to inspect, or as complementary information to elaborate cost-effective treatments. This is mainly due to limited resources and high costs associated with the implementation of RSIs. Therefore, we can often observe that either only specific road sections or only specific types of roads are actually inspected.

Aimed at developing best-practice guidelines for RSI, a survey involving 14 European countries was conducted within the scope of the EU project RIPCORD-iSEREST to determine the current practices of RSI in Europe. A *Common Understanding Approach for RSI* was then defined and agreed upon by the participants according to whom RSI is defined as [Moscari and Hollo, 2006, p. 28]:

- a preventive tool,
- consisting of regular, systematic, on-site inspections of existing roads, covering the whole road network,
- carried out by trained safety expert teams,
- resulting in a formal report on detected hazards and safety issues,
- requiring a formal response by the relevant road authority.

RSI is performed on-site and preferably by trained traffic safety experts, to be efficient. They have to identify possible problematic sites upon preliminary analysis of the road to be inspected; identify hazards while moving/driving along the road; evaluate their importance and decide if further information is needed; elaborate cost-effective measures that would mitigate these hazards without causing new ones.

During the inspections, non-conformities, adaptations and improvements according to the state-of-the-art should be taken into account. The current design standards and new methods emanating from generally accepted scientific experiences should be considered as well.

It is noted that caution should be taken to ensure that RSI does not become too similar to other safety management methods like BSM or NSM. RSI should also not become a kind of routine maintenance work, for which only the *condition* of some aspects, such as road markings, safety barriers, traffic signs etc. are checked.

Two of the main fundamental aspects of RSI are its implementation on the whole road network and its regularity. By tackling hazardous factors that were unforeseen during the design stages or that emerge during the lifecycle of a road and by dealing with possible discrepancies between existing and new build roads, RSI maintains adequate standards and consistency within the whole road network.

Guidelines for Road Safety Inspections

Taking the answers of the mentioned survey and the expected safety effects of RSI into account, a guideline for good RSI practice consisting of the following seven items were suggested by Elvik [[2006], p. 43]:

1. The elements assessed in RSIs should stand as/constitute risk factors for accidents or injuries.
2. The inspections should be standardised and designed to ensure that all elements included are assessed objectively. Checklists may be helpful in this respect.
3. Checklists should include the following core elements that are recognised as important:
    a. Quality of traffic signs, in terms of necessity, placement, legibility etc.
    b. Quality of road markings, especially in terms of visibility and consistency with traffic signs.
    c. Quality of road surface characteristics, particularly with respect to friction (macro and micro-texture) and evenness.
    d. Adequacy of sight distance; permanent or temporary obstacles that prevent timely observation of the road or other road users.
    e. Roadside traffic hazards; trees, exposed rocks, drainage pipes and culverts, steep high embankment slopes, etc.
    f. Traffic operational aspects, especially whether or not drivers' speeds are adequate to local conditions and the function of the road, suitability of the road to its function, adequacy of the space for current traffic load, separation between motorised and vulnerable road users etc.
4. To each element included in the inspection a standardised assessment should be applied, according to the following categories:

    a. Traffic hazard; should be treated immediately (a specific treatment should be proposed here).
    b. Not in perfectly good condition and/or slight deviation from current standards, but no short term action is needed, further observations are recommended.
    c. In good condition and in accordance with current standards.
5. The findings of the RSI and the proposed measures should be presented in a standardised way.
6. The inspectors should be formally qualified for their job. They should regularly exchange experiences in order to ensure a uniform application of the inspections.
7. Follow-up studies should be conducted to check if the proposed measures are implemented or not.

The Austrian Research Association[5] developed another guideline for RSI, in which it is emphasized that during a RSI not only technical aspects of the road should be taken into account, but all aspects of the driver-vehicle-road interaction that may indicate possible risk factors and can be eliminated or reduced by improving the road environment characteristics. In addition to the elements listed above, it is suggested that the following infrastructural aspects should also be taken into account during the inspections:

- Installation and sight distance on intersection with concentration on pedestrian crossings, railway transitions, cycle path-intersections etc.
- Alignment (position, height)
- Cross sections (e.g., hard shoulder, pavement/sidewalk, etc.)
- Reduction in the number of lanes
- Sight distance and sight axes from all participants point of view
- Spatial / optical guidance
- Information density / overload
- Consistency / inconsistency in information representation
- Dazzling, masking by luminous advertising and other nuisance factors
- Illumination and lamp placement/configuration
- Analysis of optical and light-technical relations/connections
- Drainage and channel flow (e.g., aquaplaning, transverse gradient, torsion, congested drains, etc.)

[5] http://www.ffg.at/

In the following we will take a look at implementations of RSI in Europe, especially in Norway, as it seems the country that takes the most effort to undertake RSIs.

Implementations of Road Safety Inspections

Because RSIs are associated with high costs, the implementations in most of the countries in the European Union (EU) do not comply fully with the guidelines mentioned above. Some EU countries do not use RSI at all. Most of the current road safety activities consist of a mixture of RSA, road maintenance inspections and black spot analysis and intervention [Cardoso et al., 2007].

Therefore, we can say that RSI is recognised as an effective tool for improving road traffic safety in many countries, but its practical implementation differs from country to country, often defined and limited by cost factors. A number of technical, administrative, regulatory, legal, and financial questions have to be solved before each country can adapt the concept in its intended form.

RSI Applications in Norway. Norway seems to be the European country who takes the most effort for RSIs. RSIs are in Norway in use since 1999. As usual they are carried out on sections with high injury severity density. Because the approach they used previously, consumed too much time during the inspection and the subsequent reporting phase, they revised it in 2005, so that the new approach requires more time at the preparation phase but less time for the surveys themselves and for post-processing and reporting (see Figure 3-5) [Handbook222, 2006].

Every step of their workflow is written down and pre-defined. It starts with a commencement meeting, where all involved parties participate in order to clarify ambiguities, define the required resources of the inspection team, present and discuss the preparatory work, and determine the schedule for the inspection and possible further meetings.

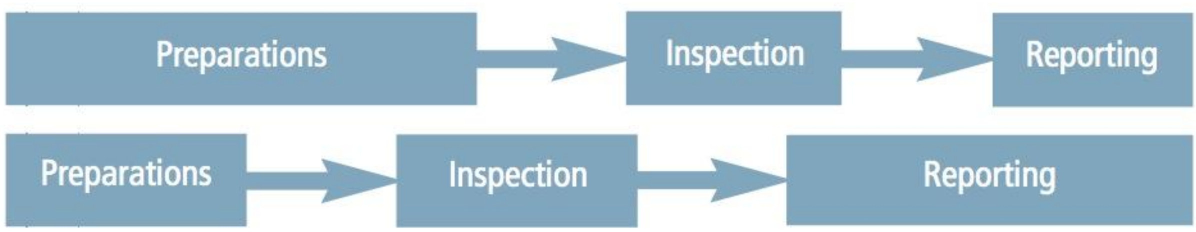

Figure 3-5: RSI methods in Norway: old (above) versus new (below)
[**Handbook222, 2006**, p. 58]

Maps of the sections that have to be inspected are important in association with data like road plans, speed limits, pedestrian traffic, etc. However, accident data is being considered only roughly. Their argument is, that a detailed analysis of past accidents may lead to focusing on particular hazards so that other hazardous conditions can be overseen. It is therefore recommended, to analyse accident analysis after the actual inspection on the road.

The inspection is undertaken in two parts. For the first part, a so called *Vidkon Inspection* is conducted, where a digital camera system is used to take pictures of the road every 20 meters. Using these pictures, the inspection team can “drive through” the section at the office (see Figure 3-6) before undertaking the real survey, in order to get an idea of overall factors, such as signings, markings, intersections, the road design etc [Cardoso et al., 2007].

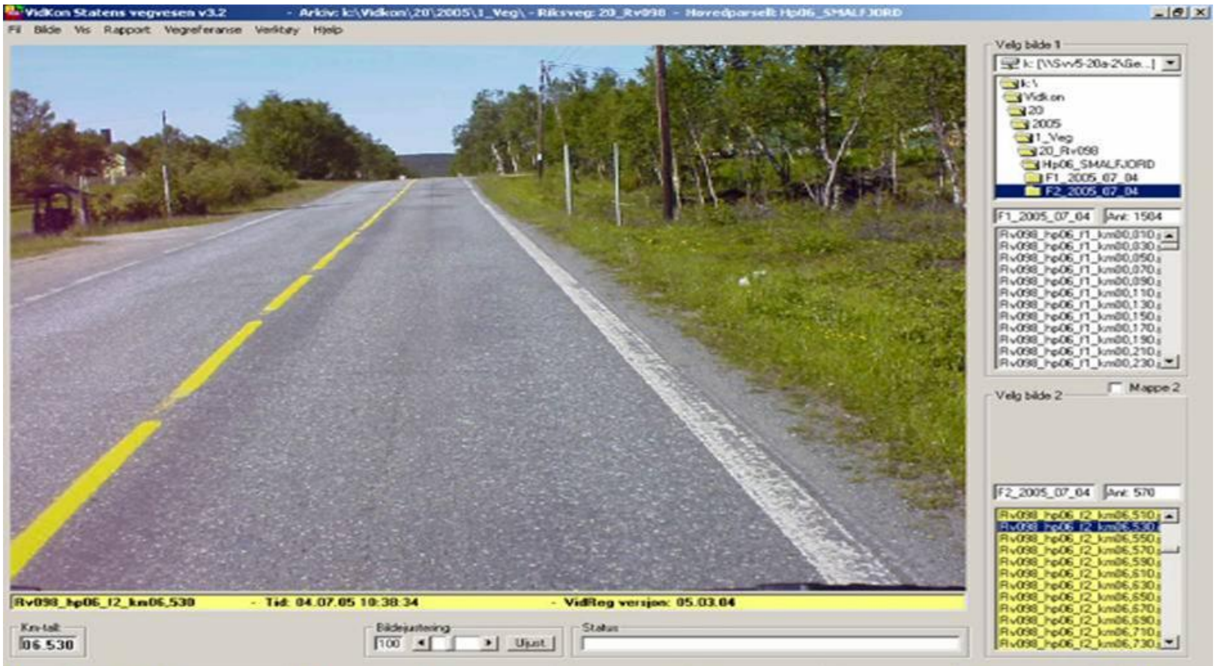

Figure 3-6: Screenshot of the pictures taken during a Vidkon Inspection [**Cardoso et al., 2007**, p. 23]

The following points are declared as not easy to recognize with the Vidkon Inspection and should therefore always be checked during the actual survey [Handbook222, 2006, p. 67]:

- Ditch areas
- Side slopes
- Breakway poles and pylons
- Intersection and access drive sight zone
- Side road signing

- Conditions on pedestrian and bicycle facilities

The next step is the field inspection itself, for which the results of the Vidkon Inspection serve as a basis. On the one hand, unsettled findings can be observed on the spot, while on the other hand, measures for the detected hazards can be elaborated.

The reporting of the results of the inspection are also standardised in Norway. The "T-ess" called forms are generated in Excel to allow easy filling of common information and to use macros to retrieve standard text. For each direction of the survey there should be one or more files, where it is recommended to have a maximum of 40 findings in one file in order to keep the file size small. The common information like route number, section name, direction etc. is entered only once when the file is opened. This information is then available for each report in this file. The following specific information has to be entered for each finding;

- Kilometre identification of spot/find or km from-to for a section
- A problem description for the find
- Tick off for deviations, faults or remarks
- Tick off for finds considered to be an immediate or an investment measure
- Photo of the find (from Vidkon and/or from the inspection)
- Description of proposed measures

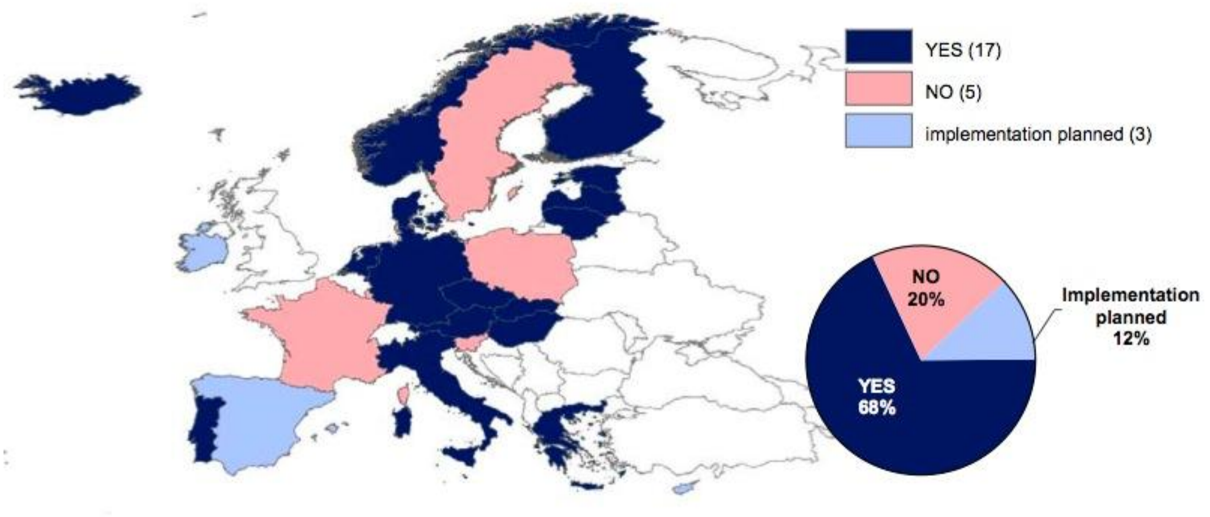

Figure 3-7: Status of RSI implementation in Europe [**HLEM, 2006**, p. 37]

RSI Applications in other European countries. Within the scope of the RIPCORD iSEREST project[6], a questionnaire with experts from 34 countries was performed in 2005, where the result was published 2006 in Vienna. The questionnaire covered most of the road safety related topics, including RSI. The results showed that among the countries who replied, 17 countries had a RSI implementation, 3 were planning it in the near future, and 5 did not perform RSIs (see Figure 3-7).

3.4 The European Road Assessment Programme

The European Road Assessment Programme (EuroRAP)[7] was piloted in 2001, as a sister programme to the European New Car Assessment Programme (Euro NCAP), in four countries and has now launched in twenty European countries. The methods used by EuroRAP are also applied in Australia through AusRAP and in the United States through usRAP. Furthermore, the know-how gained at the most advanced programmes are being transferred to Africa, Asia, and Latin America by the international Road Assessment Program (iRAP).

EuroRAP aims to provide independent, consistent safety ratings of high-risk roads across borders where large numbers are killed or seriously injured and to identify affordable high-return countermeasures. The aim has been to cover a network of interurban roads on which at least 30% of national fatalities occurred. The pilot programme was planned in three parts:

- general international comparisons of death rates on the road network in different EU countries,
- analysis and mapping of fatal and severe accident rates on major roads outside built-up areas,
- inspection of the safety quality of the road infrastructure to identify to what extent they protect road-users from accidents and from death and serious injury when accidents do occur.

Within this framework Risk Maps were introduced and developed that allow the identification of higher risk routes and enable performance tracking over time and detailed analyses of accident patterns on different roads. Furthermore, road inspections led to the current Road Protection Score, which focuses on assessing the quality of the road infrastructure.

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[6] http://ripcord.bast.de/
[7] http://www.eurorap.org/

3.4.1 Risk Maps

EuroRAP uses accident data to provide risk ratings in form of maps showing the density of traffic collisions that caused death and life threatening injuries. They highlight sections of road where intervention may be required to reduce the likelihood of collisions.

Two types of risk maps are presented. The first plots the annual average number of fatalities per road kilometre, is referred to as the 'collective risk map' and presents the crash density. The second type of maps plot the number of crashes per vehicle kilometre travelled and are referred to as 'individual risk maps', as they show the risk for individual drivers, calculated by dividing the frequency of crashes per annum by the distance travelled on each road link per annum [Smith, Daly and McInerney, 2007, p. 3].

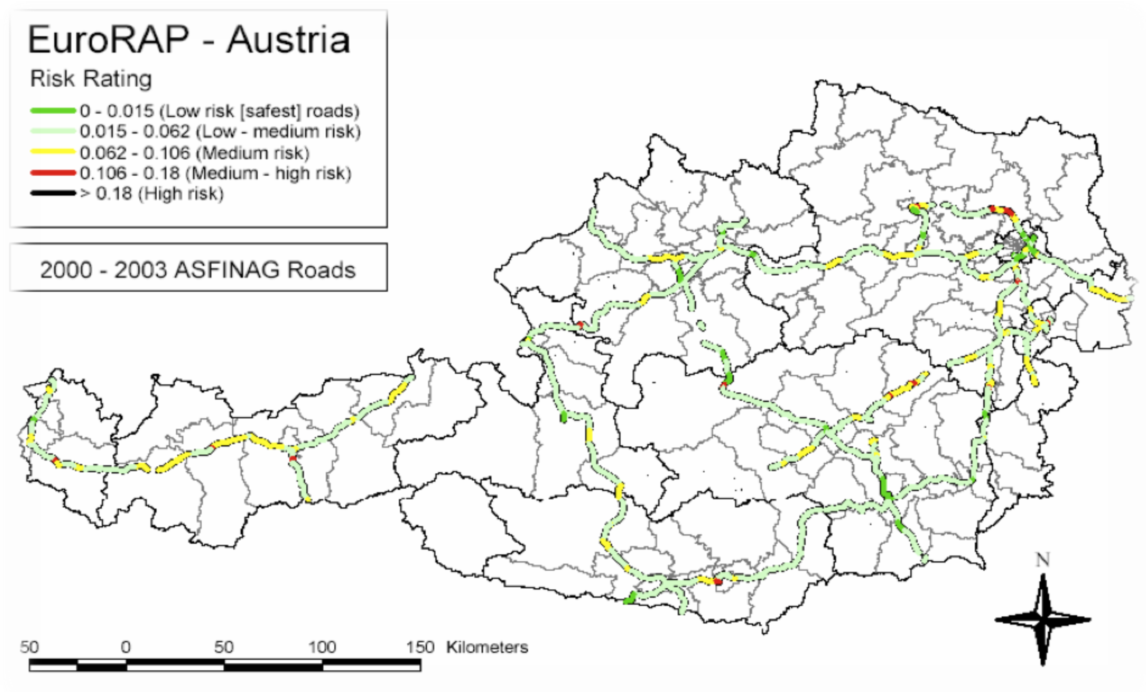


Figure 3-8: Risk map of Austria for the years 2001 - 2003 [8]

3.4.2 Road Protection Score and Star Ratings

Within the scope of EuroRAP, road inspections are carried out with the aim to produce a score for each route section that enables it to be compared with other sections. This *Road Protection Score* (RPS) focuses on the road design and on road-based safety features. The required data is recorded by in-car assessors using a tablet linked to a GIS database (see Figure 3-9).

[8] http://www.eurorap.org/risk_maps

Figure 3-9: Equipment to record road protection descriptors [**Lynam et al., 2007**, p. 41]

The scoring software takes the data directly from the database and presents the RPS results in form of star-rated maps. The used *Star Rating* is based on the RPS, where one to five stars are awarded to road links, depending on the potential quality of the road infrastructure (see Figure 3-10). The RPS can be presented in the aggregate for all accident types or for individual accident types (head-on crashes, run-off road etc.) showing the different ratings along the route.

In its current form the RPS does not include the likelihood of an accident occurring: currently “protection” refers only to the protection from injury when accidents happen [Lynam et al., 2007, p. 41]. Thus a high score will not necessarily reflect a low accident rate, as only part of the risk is being scored. It should rather demonstrate that for a given number of accidents, a lower proportion of them would result in fatal or serious injury.

But a second component is being added to the rating system, which includes road infrastructure features that affect accident likelihood. The two factors will be combined in a risk matrix to provide an overall assessment of risk [Lynam et al., 2007]. The use of a risk matrix is a technique commonly used in risk assessment. It enables total risk to be seen as the combination of the likelihood of an event (accident) occurring, and the resulting potential consequence (injury severity). Reducing the effect of either factor alone, or of both together can reduce the total risk. To use this approach in the RPS, the component factors, which contribute to the variables on each axis, have to be defined and assigned with a risk relative to each other. For example, roads with wide lanes (greater than 3.6m wide) receive a better score than roads with narrow lanes (less than 2.8m wide), as they leave more room for error than the latter where the risk of a crash is 50% higher. Or, roads with wide sealed shoulders (greater than 2.4m) receive a better score than roads with no sealed shoulders where the risk of a crash is 60% higher [AusRAP, 2008, p. 7].

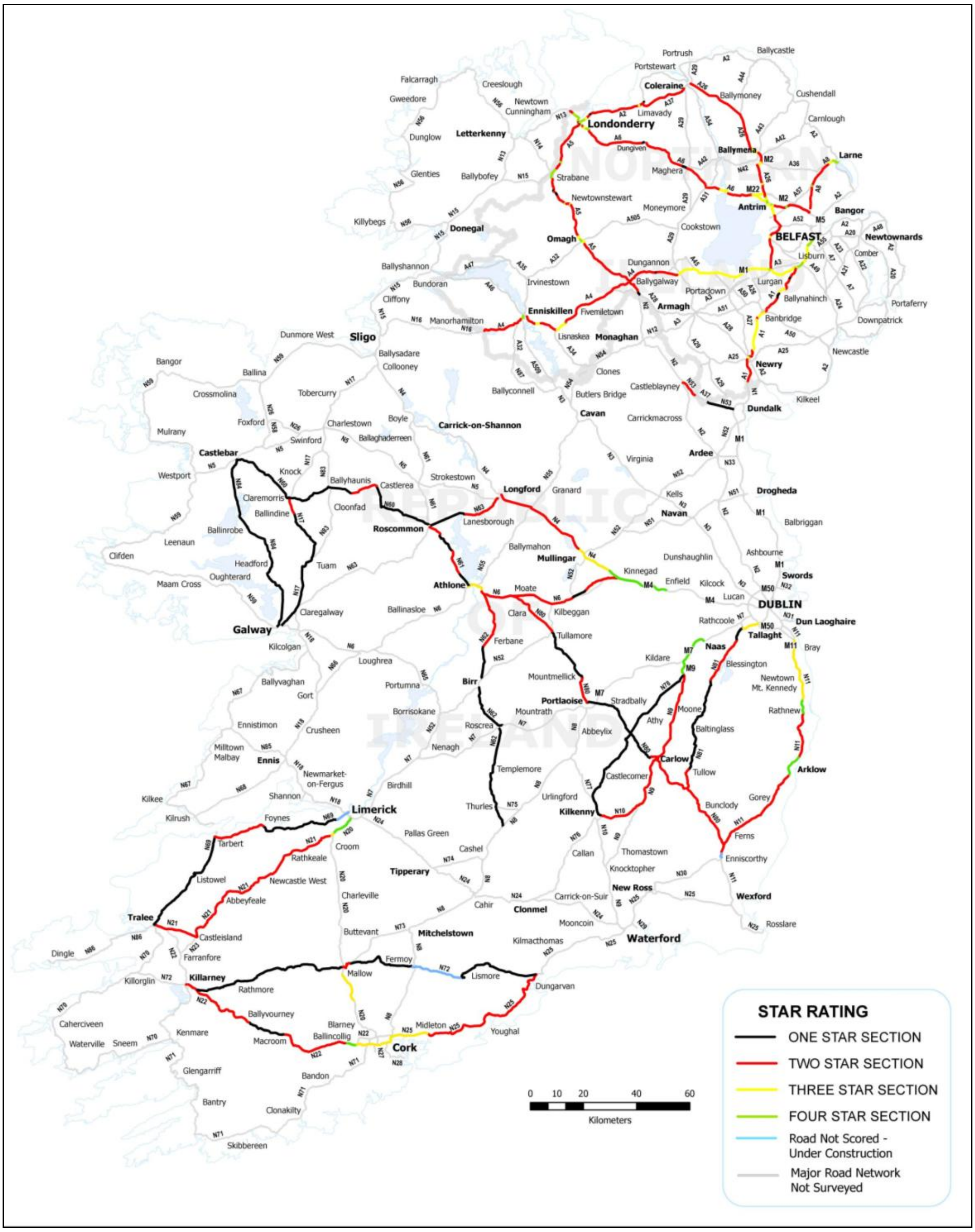


Figure 3-10: Star rating for major roads in Ireland [9]

The ratings for each individual component will still be identifiable so that the engineer knows which aspect of the infrastructure needs improving. Such a combined assessment is already used in AusRAP, although the two components are not distinguished separately.

[9] http://www.eurorap.org/rps_maps

iRAP set its focus also on developing the rating system further. In many countries, the number of pedestrian deaths is high on both urban and rural roads. This requires the rating to be extended in two ways – both to take account of urban environments, and to consider the likelihood and protective factors associated with vulnerable road users, particularly motorcyclists. Research information on these factors in terms of their influence on risk is less extensive than that pertaining to car occupants, and the linkage between vehicle and road design is less clear, so these developments remain a difficult challenge but will form one aspect of future EuroRAP work [Lynam et al., 2004].

The particular focus that RPS provides together with the simply rating by accident numbers or rates, highlights the extent to which observed high accident numbers result from poor quality of the road design.

In this chapter several methods used for Road Safety Assessment were examined, each with its own advantages and disadvantages. As mentioned earlier, these methods are complementary and promise the best results when applied combined. It has been the objective to analyse to which extent approaches from the field of Computer Science can be used to facilitate these individual methods while at the same time addressing their disadvantages. The result is the Road Traffic Safety Framework, which is a comprehensive framework that addresses the most important aspects of all methods, namely to gather and analyse data. The following chapter contains a detailed description of the proposed framework and outlines the path for its implementation.

CHAPTER 4

4 Road Traffic Safety Framework

Improving road traffic safety is an important issue in the European Nation and most developed countries. Many studies and projects are conducted, trying to approach the goal from different directions. In this thesis the Road Traffic Safety Framework (RTSF) is introduced and proposed. The RTSF aims to provide road traffic engineers with techniques and methods from the Computer Sciences in order to facilitate their tasks and to increase their knowledge.

As seen in Chapter 2, road traffic is a complex system with several components and many sources of risk. The proposed framework concentrates on the third component of the road traffic system, namely the road and its surroundings. However, the framework will contribute to the research regarding the other factors as well, as it will lead to more data and hence more knowledge.

Improving the safety of the road requires the detection and elimination of hazards on the road and its surroundings. Looking from the perspective of a computer scientist, the procedure of detecting the hazards and suggesting appropriate measures can be split into three steps: gathering, storing, and utilising data.

In this chapter it is described in detail how the proposed framework approaches these three steps. The questions which computer systems are necessary, how they can be developed and implemented, which benefits are expected to bring about will be answered, and an estimation of the expected implementation costs for some parts will be given. The framework itself can be considered as an assembly of all these systems defining their interactions and the general workflow.

The framework is intended to be used and supervised by the government, while the implementation of the internal systems should be in the responsibility of different local authorities, based on the bureaucratic structure of the respective country to ensure shorter development times and a smooth countrywide implementation of the complete framework.

The framework addresses two types of users. On the one hand, the authorities can use the framework to perform practical improvements on the road by fixing the detected hazards. On the other hand, researchers can use it as a powerful tool for analysis and knowledge discovery. Due to the high quantity and quality of the gathered data, the data is not limited for the use for road safety research, but can also be utilised to analyse the effects of the other factors, such as human behaviour and vehicle design.

4.1 Gathering Data

Accident data is currently the most used and available form of data for road safety analyses. However, their quality and coverage is limited. Gathering data is considered as one of the essential parts of the framework while the interest lies mainly on three types of data: data about the road and its surroundings, conflict data, and accident data.

4.1.1 Gathering Data About the Road and Its Surroundings

It is important to know the characteristics of the roads and their surroundings in order to derive conclusions about safety hazards that may lead to traffic conflicts and accidents. Therefore, this kind of data is considered as the most important one to gather.

Road Safety Inspections (RSI) provide detailed information about the road and its environment by covering the inspection of constant structural characteristics (e.g., entries, tunnels, etc.) and unsteady characteristics (e.g., road marks, vegetation, etc.). Because of the extensive nature of information that RSIs can offer, the common understanding is that they should be carried out periodically and on the whole road network. However, even though there are some variations in the best practice of some countries, all of them are very time consuming. This circumstance hinders their periodical implementation over the whole road network and leads to only seldom inspections on selected areas of road network. Therefore, this kind of data is not widely available when compared with accident data.

If one takes a look at the roads in Austria, for instance, there are 2.000 km of motorways and freeways and 35.000 km of federal roads. The costs for a road safety inspection on freeways is estimated to be 10.000 € per 10 km, resulting in 2.000.000 € for the whole freeway network. If one assumes similar costs on highway inspections, this would result in another 35.000.000 € for the highway network. Minding the recommended periodical implementation of the inspections, the costs for the whole network to be inspected, excluding the 80.000 km of municipal roads, would be around 100.000.000 € in 10 years.

Given the importance of data that can only be gathered through RSIs, one major objective of the framework is to provide cost-effective means to enable the periodic and extensive implementation of RSIs. For this purpose the development of a computer aided RSI system is proposed, which will be explained in more detail in the following.

Computer-aided Road Safety Inspection. A RSI consists of several workflows that can be facilitated by computer systems. These workflows are the on-site inspection, the post-processing of the captured data at the office, and the compilation of reports using the processed data.

The workflow of the **on-site inspection** consists of the preparations and the road survey itself. Administrative preparations such as defining the road sections for inspection and so forth have to be easy to undertake. Further, the user should be given the possibility to register data about known peculiarities of the road sections, such as black spots or known dangerous areas, in order to pay more attention to those sections during inspection.

The course of the survey should be recorded using GPS, so that the localisation of the registered events is done automatically and the inspector can concentrate on his task of identifying and registering event. The event that have to be observed should be defined in advance in form of standardised checklists, so that the inspector knows what he is going to look for and so that surveys carried out by different inspectors can be easily merged. The developed computer-based surveying system should enable the inspector to register a detected event fast and with minimal effort. This can only be guaranteed with a well-designed graphical user interface.

Further, some registered events require the input of additional information. Writing them down during the survey, especially on freeways and highways, is not an option for obvious reasons. Therefore, the user should be given the possibility to easily record voice memos, either for individual hazards or for the entire survey. This will enable the inspector to collect more information in one survey, so that the same section has not to be inspected several times to capture all of the relevant information.

Another useful complementary aid to collect more information about individual hazards or the entire survey is the use of visual data in form of photographs or videos. The required equipment could either be controlled by the computer system so that the recorded data would be automatically linked with the gathered data during the survey (e.g., location, hazards, etc.) or the equipment could be controlled manually independent of the computer system. The second way is easier to implement from a technical point of view and would not require additional special equipment, however, it would require a little more effort during the post processing phase at which the photos and videos would have to be synchronised with the data collected during the survey using time stamps.

The **post-processing** of all the collected data is time consuming and difficult to undertake with existing methods. A computer aided RSI system, therefore, should be designed in a way to ease the tasks related to this phase. Because the hazards had been defined in the preparation phase and the localisation of the registered hazards had been done during the survey itself using GPS, the inspector has only to control the collected data and to add optionally additional information using the recorded audio and visual data.

The **reporting** should be automated by using predefined templates. Mind that the mentioned reports are only written reports for the authorities and focus on giving an overview of the survey and the registered hazards.

Organisational workflow of RSIs. The bureaucratic procedure of deciding which road sections to inspect, announcing the project, contracting an inspector, and receiving the results is for itself very time consuming and hence, causes additional costs. Carrying out RSIs for the whole network following a given periodical timetable would standardise their procedure to some extent.

However, it is suggested that inspectors employed directly by the responsible authorities should carry out RSIs. This way the authorities will save the time consuming bureaucratic procedure. In the following, several calculations are given to show the potential of the proposed computer system to cut off the costs for RSIs significantly.

Current and expected costs of RSIs. Looking at the freeways in Austria, 2000 km of road has to be inspected. With the proposed procedures, a team consisting of 2-3 experts can easily survey a route of 100 km in both directions in one day. Theoretically the whole network could be inspected in 20 days, but we recommend the post processing to be performed shortly after the on-site inspection. A good trade-off seems to be to carry out survey for two days on a route of approximately 200 km and then to perform the post processing for these routes in the following three days.

So a team could inspect 200 km of road per week, resulting in a total time demand of ten weeks for the whole freeway network with one team, or of five weeks with two teams. The number of the required teams should not be based only on the length of the road network, but also on the spatial spreading of the roads. Located at the centre of the road network, a diameter of about 350 km seems feasible for one team. This short time that is required to perform a survey would enable the authorities to perform multiple inspections during one period, so that it would be possible to carry out not only the suggested inspections every two years on freeways, but also to perform special inspections, like night-time and winter-time inspections, for the whole road network in the same period.

This timesaving leads directly to lower costs. The above mentioned team with two additional secretaries would have an estimated salary of about 200.000 € per year. Adding incidental costs, such as hardware, software, fuel costs etc., we can assume a yearly cost of 250.000 € to pay in order to gain very detailed insights about the condition of the freeways and its surroundings.

Similar calculations can be made for the highway network. One team can inspect 4000 km of highway roads in six months, so that considering the time for vacations and occasional additional work, two teams would be sufficient to perform inspections over the whole highway network within the period of four years. Summing up these costs for these three teams over ten years, we get a total of 7.500.000 €. Compared with the costs of 100.000.000 € calculated before, this means a reduction of over 90 percent, while at the same time increasing the amount and quality of the gathered data.

4.1.2 Gathering Traffic Conflict Data

The second type of data that must dealt with are conflict situations on roads, which do not result in accidents but are important nevertheless, as they indicate the existence of safety hazards that might lead to accidents. Even though conflict data is not absolutely required for the framework to function properly, it is recommended as it has some important qualities. First of all, due to the similar nature of conflicts and accidents, such data is of great value for determining the safety potential of a section, its design, and infrastructure. The main benefit compared with accident data, however, is its preventive nature, because by analysing conflict data, hazards can be detected before any accident happen, which is useful to evaluate the safety of especially new roads. Furthermore, it can provide us with valuable information about safety deficiency types yet unknown and therefore not covered by RSIs. Analysing conflict data can therefore lead to improvements and corrections of the predefined list of deficiencies used for RSIs.

As seen in Chapter 3, the techniques to detect conflicts are very resource demanding, because a team with an expert with special training has to observe a single spot, like a junction, over a specific time period, usually for 3-5 days. The observation process itself is hard to automate, because the common sense of the expert is needed to identify conflicts as such. Assisting the expert with video footage of the observed spot, for instance, would be possible and also increase the quality of the data, but would not lead to a decrease of the costs.

If one takes Vienna as example, there are approximately 5000 junctions. One would have to film each junction for four days, which would mean 480.000 hours of video footage. If there would be more than one camera to cover different angles, which could be necessary to have a sufficient overview of the junction, this amount would increase even more. Even if one would assume that existing software could analyse these videos and detect the conflict situations so that the expert would only have to watch a fraction of the total length and would, let's say, need one day per junction, still 5000 man days would be necessary to cover the junctions in Vienna only. Even if a system existed that could decrease the needed manpower, the costs for the technical equipment, the setup and dismount of the video system, the administration of the huge amount of digital video data etc. would be too expensive for a real implementation.

Because of these reasons, the proposed framework suggests a new approach to gather data about traffic conflicts, which might lead to a decrease in the quality of the data but enables the gathering of more data, so much so that the high quantity could compensate the possible loss of quality.

The idea can be summarised as gathering the basic data from participants of traffic conflicts and validating them by experts or using statistical methods. In the following the basic architecture of the proposed computer system for that purpose and the proposed method to administer the collected data is outlined.

Online Conflict Reporting Portal. The development of an online portal is proposed, which allows a road user to report a conflict he was involved in or had observed. Because the only benefit for the user is the possible improvement of road safety, the system has to be user friendly, and the reporting process intuitive and not time consuming. One can assume that the average user of the system is not going to have training in using such a system. Therefore, the interface has to lead the user through the whole reporting process step by step, while trying to get only relevant information about the conflict situation.

First, the location of the conflict has to be determined. The user could either give the address or select the spot on an interactive map. Before the user gets to the interface to enter information about the conflict itself, he should see a list of already reported conflicts in the same area. If a certain spot, for instance, has a significant design error that leads often to conflicts of a specific kind, it is likely to be reported more than once. In such a case it is easier for the user to confirm the existing report and to optionally add some additional information, rather than generating a new conflict report. Also the system should periodically check the conflicts located in a close proximity to each other in order to identify conflicts on the same spot, so that the system administrator can review and merge them.

The next step is to describe the conflict situation sketchily. This should be done on a draft of the given location with a toolset of predefined elements like traffic signs, different vehicle types, plants etc. The draft of the road can be generated using data from road data distributors, like Teleatlas[10] or Navteq[11], with additional information, such as positions of traffic signs or bikeways etc. this step is going to be the most difficult to handle, especially for inexperienced users. Therefore, detailed tests with potential users should be carried out during the whole development phase of the user interface. The main objective is to help the user to sketch the conflict situation easily without needing to add much written explanation, so that a road-planning expert can reproduce and understand the conflict situation accurately.

Afterwards, relevant information, such as the user's subjective opinion about the level of threat, the classification of the conflict, the main cause (e.g., road design, driver error, etc.), or suggested measures, etc. can be requested.

To make the system more attractive for users and increase their participation, social elements like commenting on other reported conflicts or discussing them, eventually with statements from road planning experts, should be also implemented. Another important point with this regard is to keep the user informed about the process of his report. The user should be

[10] http://www.teleatlas.com/index.htm
[11] http://www.navteq.com/

informed when his report was controlled and accepted, when measures from an expert were suggested, and whether these measures are going to be implemented and when.

Administering Conflict Reports. The second part of the system concerns road engineers who have to control and evaluate the significance of the reports. An interface to browse through the reports, sorting them by date or location etc. is needed. But much more important is how the engineer can reproduce the reported conflict. If the conflict is mainly caused by road design elements, the given sketch should be sufficient. However, sometimes it will be necessary to decide, for instance, if the visual angle from the main street over the bikeway is really insufficient while turning left. At this point the only option would be to make an on-site inspection. Therefore, such reports could be marked for later inspection, so that inspections for conflicts within the same area can be carried out at the same time.

However, the use of a new technology is proposed to reduce the number of necessary on-site inspections. We are referring to the 'street view' technology by Google Inc. (see Figure 4-1). Cooperation with Google at this point should be envisaged. Google Inc. already has the technical equipment and know-how to get, store, and use the visual data of the streets and both sides would benefit from comprehensive street views. Depending on the actual costs the developer team of the framework should select the extent and the area to be explored for *street view*, based on the incoming conflict reports.

Figure 4-1: Street view of an intersection as provided by Google Street View

4.1.3 Gathering Accident Data

Accident data is the most used data source in the field of road traffic safety. Because analysing them can provide one with useful information about safety hazards regarding all three factors of the road traffic system, one of the major objectives of the road traffic safety framework is to improve the methods to gather information about accidents.

Within the framework three types of accidents are distinguished, whereas it has to be stated that this is more a practical distinction than a scientific one. First there are accidents with fatalities, serious injuries or severe property damage, which are normally reported to the executive. Then there are accidents with only little property damage and no or only little injury, which are only reported to the insurance companies. And then there are accidents with no or very small property damage where the participants come to an agreement at the sport and the accident is never reported anywhere. The framework should deal with all three types and, therefore, has to provide the necessary means to gather data about all three of them.

The first type of accidents, that is, accidents with fatality or severe injuries are indicators of significant hazards within the road traffic system. Therefore, it is very important to gather accurate data by collecting existing data about past accidents on the one hand and, by providing the executive with means to gather more detailed data about current accidents, on the other hand.

Currently, accident data is mostly available in form of accident reports, which often differ in structure and their level of detail. As it would be very time consuming to enter all of these reports manually into the framework's storage, methods have to be developed to automatically import them.

Besides accident reports, another source of accident data are national or international databases like the CARE database[12] on roads accidents resulting in death or injury. Even though they usually contain aggregated data that is focused on certain aspects of accidents (e.g., only the number of resulted fatalities) it should be possible in the system to import this information in order to make analyses in connection with the otherwise collected data.

To capture information about current accidents of the first type is not going to be very difficult, because the executive has to gather data about such accidents anyway. A computer-aided system that eases their standard procedure and decreases the amount of the necessary post-processing will be gladly accepted by the executive, as long as it is easy to use. Therefore, the design of the system's user interface has to be developed in close cooperation with the executive. Because most police vehicles are already equipped with computer systems

[12] http://europa.eu.int/comm/transport/home/care/index_en.htm

or handheld devices, the system should be implemented in a way that allows it to be used with these devices in order to avoid unnecessary costs.

To gather data about the second type of accidents is more complicated, not from a technical point of view but from an administrative one. Currently, most of these accidents are being reported by the participants, using the standard accident report sent to their respective insurance companies. At the minimum, statistical data from the insurance companies should be collected to gather information about this type of accidents. This might require a lawful basis, especially because of privacy reasons. But because the system does not need personal information about the drivers, but only statistical data, and because the insurance companies themselves are going to benefit from the results of the extensive analysis done by the framework, it is highly probable that an agreement can be achieved.

A more complex way to deal with this second type of accidents, which would increase the quality of the data, requires closer cooperation with the insurance companies. If the accident report could be accessed and filled electronically, so that it would be more comfortable for a participant to report the accident online, rather than filling up the standard paper report, more information about the accidents could be gathered without any additional effort. The success and acceptance of such a system highly depends on the willingness of the insurance companies to offer this service to their clients and to reward them for using it. We propose a system similar to the Online Conflict Reporting Portal presented in Section 4.1.2.

The last type of accidents is the most difficult one to collect data about. Because there is no need and no benefit for the participants in reporting the accident, such data has not been collected so far. However, in order to not neglect data about this accident type, it is proposed to treat such accidents as conflicts and to use the Online Conflict Reporting Portal to gather data about them.

4.2 Storing Data

In the previous subsection, the three main sources of data relevant for the framework were listed. Gathering this data is the first task of the framework, the second part is about how this data has to be stored and managed efficiently. The suggested methods for this purpose are not innovative, in the sense that they are common techniques from the field of Computer Science. However, the utilisation of these techniques in the field of road traffic safety to this extent can be considered as new.

There are two widely used methods to store data in a way such that it can be easily accessed, managed, and used afterwards. The most common way is to use databases, especially if one deals with a huge amount of data and needs frequent access to the data in several ways. The second way is to use structured text documents, which are often used for storing little quantities of data, such as XML documents.

It was already mentioned that, in order to provide flexibility of the framework to be used for different application areas, the framework outlines the system in terms of the functions it has to fulfil and not in terms of their detailed architecture. This objective of developing a flexible system requires that the data structures to save all the gathered data has several properties:

- **Adaptable.** The framework is intended to be an evolving system, where the gathered data is utilised to perform analyses to gain new knowledge, which then can be used to adapt the framework. Therefore, it has to be possible to change the underlying data structures as well, without affecting the access to older data.
- **Extendable.** As a special case of adaptation, the data structures have to be extendable, which means that the main data structures do not change, but are augmented with new attributes.
- **Interoperability.** The framework consists of several subsystems, each one of them having its own underlying data structure. It is essential that these systems can exchange data between themselves and can understand each other without much human intervention.

These requirements motivate the 3-tier architecture, shown in Figure 4-2. As one can see the lowest level of the architecture is based on XML. Each one of the introduced three systems to gather data use XML documents to store and manage their own data. Because XML documents are machine-readable and deliver the definition of their data structure with them, exchanging data between the subsystems is very easy. If the data structure has to be adapted or extended, this does not affect old data, because the system can understand the old structures as well as the new one.

For the local management of the data and especially for the dynamic nature that is proposed, XML fulfils the requirements perfectly. However, for dealing with huge amounts of data, XML is not the best choice, because the files have to be read-in first as a whole every time the system wants to access any part of the content. This leads to the second level of our

3-tier architecture, the databases where the gathered data from the three data sources are stored.

The data transfer from XML documents into a database is a standard procedure and can be easily automated. The main problem in this case is to maintain the flexible data structure. It is assumed that the system will need an adaptation of the underlying data structures, every two to four years, depending on the growth of knowledge that is gained through performed analyses with the data.

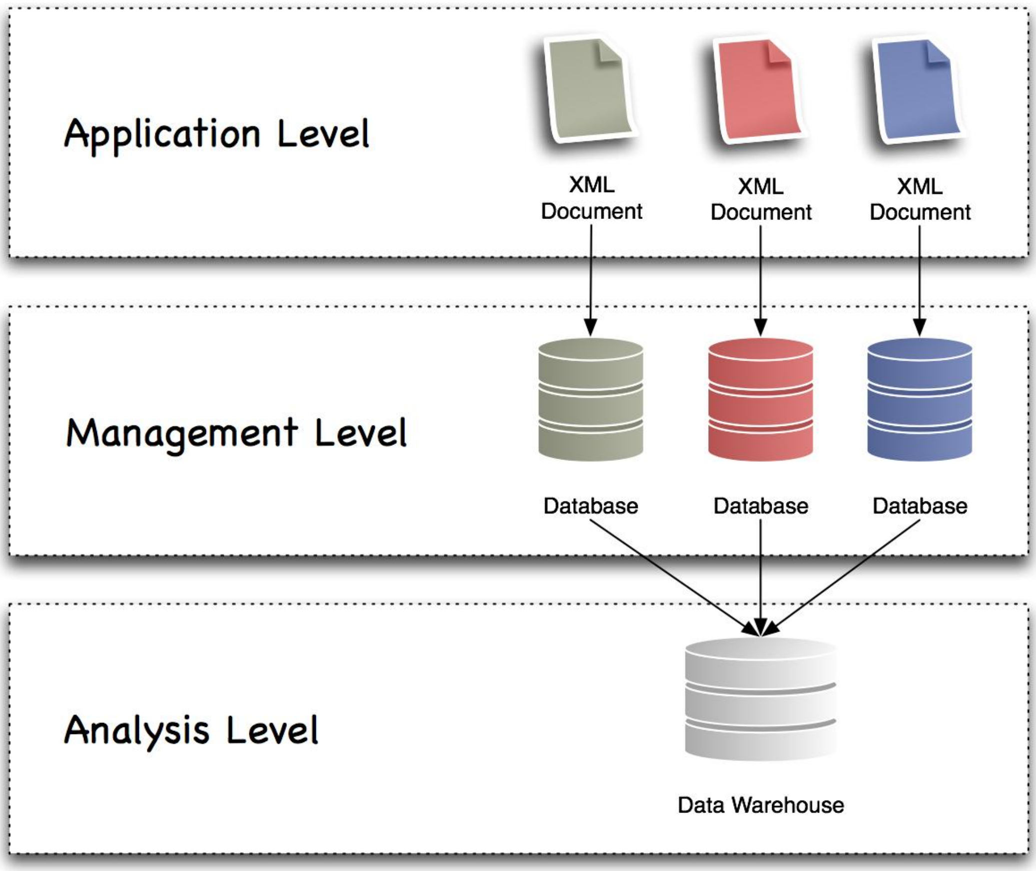


Figure 4-2: Data Architecture of our Road Traffic Safety Framework

Keeping the old data model of the database and trying to translate the new data structure in a way so the information can be stored within the database is not an option, because it would cause data loss. Changing the data model and adjusting the other systems that use the database is a difficult task, but in principle possible. The main difficulty here is to manage and translate new queries so that the user has not to worry about the different underlying data models of new and old data and can access them seamlessly.

The framework suggests therefore minimising the use of static data structures within the data model. For instance, each accident has obviously a location where it happened. Normally one would save this location information directly in the table of accidents as the *address* of the accident. If the model has to be changed later in order to define the location of accidents with GPS coordinates, the adaptation of the old data would be difficult. A flexible and dynamic model, however, would save the location information in a separate table where each accident would refer to one entry in the location table. So that the user could still perform location-based queries and the system would automatically use the address information for old and the coordinate information for new data.

Designing and implementing such a dynamic data model is understandably more complex than designing a standard data model to fit the actual needs. However, it will make adaptations in the future much more easier and is therefore highly recommended.

The third tier of the data architecture (see Figure 4-2) is the data warehouse. A data warehouse's objective is not the storage of data. For this purpose the databases at the management level would have sufficed. However, the overall access to the data in these databases is not feasible using standard methods for relational database management systems. The data warehouse fills this gap and allows queries among data from different sources. Because the technology is a little bit complex and the data warehouse can be essentially considered as the core of the proposed road traffic safety framework that enables us to perform several analyses to acquire new knowledge, it is explained here in more detail.

A data warehouse is basically a database as well, as it also stores data. In fact it gets its data from several existing databases. So one may ask why one has to save the same data twice. The reason lays in the difference a database and a data warehouse can access and make use of this data.

A classical database is designed for transactional use. In a business environment an order or a sale are standard examples of transactions. In our case each accident, traffic conflict, or hazard would be a transaction, saved in the database. The data in database can be accessed, filtered by attributes such as accident type or a time interval, and so forth. Simple aggregations like retrieving the number of accidents of one accident type in a specific time interval would also be possible. A database is optimised in its structure and management system for such uses.

Analysing data, especially from different sources, by stating several constraints however, is not a trivial task and would be very time consuming to perform with traditional methods available for databases. Because of this shortcoming the Online Analytical Process (OLAP) has been introduced. With this approach, the data is arranged in a multidimensional cube, also called an OLAP-cube or Hypercube that allows performing different operations to analyse the data. Two terms that are used within this context are *facts* and *dimensions*. To understand these terms better a practical example from the grocery industry is given below.

Imagine a supermarket chain with many branches all over the country. The facts, which are usually numerical values, can be the number or volume of sales. In this case, each sale is a fact and as such is an entry in the so called fact-table, containing a lot of indexes pointing to different dimension tables, which contain information about the products, the branches, the dates of sales, etc. In Figure 4-3 an example for such a formation is showed, which is called a star-schema and is widely used in data warehouses.

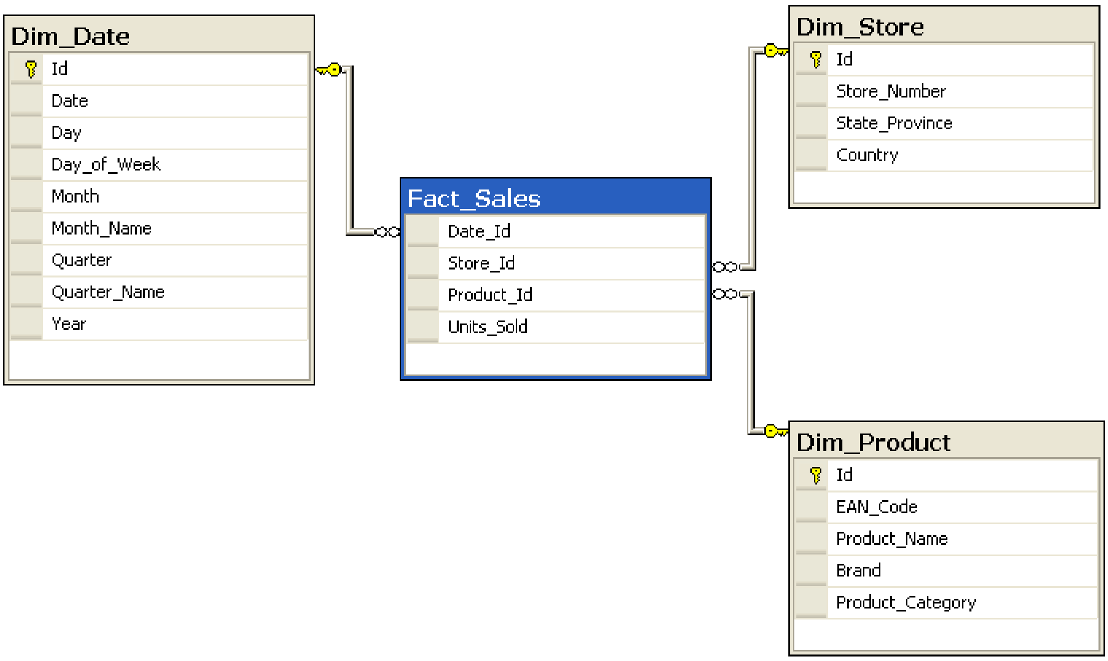


Figure 4-3: Example for a Star-schema

Now the OLAP-cube can be built out of this star-schema to look at the operations that are possible with it. The cube in this example has three dimensions, but there is no limit for the number of dimensions. The dimensions here are product, store, and date. Thinking of it as a three dimensional matrix, each cell contains the sale of the corresponding product in the corresponding store at the corresponding day. Note that the dimensions have in general a hierarchical nature. Products can be aggregated by several product groups, the stores can be aggregated locally by regions, cities and countries, and the date can of course be aggregated by weeks, months, and years.

The main operations defined by the OLAP Council that can be performed with OLAP cubes are slicing, dicing, drilling down/up, rolling up, and pivoting[13]:

- **Slicing:** A slice is a subset of a multi-dimensional array corresponding to a single value for one or more members of the dimensions not in the subset. From an end user perspective, the term slice most often refers to a two-dimensional page selected from the cube.
- **Dicing:** A dice is a subset like a slice, with the difference that it is multi-dimensional.
- **Drilling down:** Drilling down is a specific analytical technique, whereby the user navigates among levels of data ranging from the most summarised to the most detailed. The user can, for example, drill down from the country Austria to the city Vienna.
- **Rolling up:** Is the opposite of drilling down, going from the view of the cities to the overview of the country, consolidating the values.
- **Pivoting:** Is also called rotating and allows the user to change the dimensional orientation of a report or the page display.

To design a data warehouse, that is specifying fact and dimension tables, is more complex than designing a classical database. The design of the data warehouse that is to be used within the road traffic safety framework has to be done by an expert in cooperation with a traffic engineer, while considering the designs of the three databases from the management level.

The interested reader is referred to the book *Building the Data Warehouse* by William H. Inmon as a good introduction into this field, and the book *The Data Warehouse Toolkit* by Ralph Kimball and Margy Ross that contains examples of data warehouses from several fields, such as education, health care, transportation, etc. Another interesting reading would be the dissertation by Nevena Stolba from the Technical University of Vienna with the title "*Towards a Sustainable Data Warehouse Approach for Evidence-Based Healthcare*", in which the author introduces a data warehouse in a field where it has not been used before.

Another important question at this point is how the data from the databases at the management level are going to be transported into the data warehouse. This process is called ETL, which stands for Extract, Transform and Load.

At the first step the data is extracted from several sources, which can have different formats, such as relational databases or unstructured text files. In the proposed framework the

[13] http://www.olapcouncil.org/

main sources are the three databases at the management level for accidents, road and environment, and traffic conflict data. But additional data from external sources, such as weather information from existing excel sheets can be extracted to be used within our data warehouse, also. Within the framework, the extraction process has to be performed on a regular basis, either periodically or event triggered. It can cover the entire database or only the changes since the last extraction.

The data, coming from different sources in different formats has to be transformed into the model of the data warehouse to make them compatible. The syntactic transformation covers the revision of data types like bringing all dates into the specified format (e.g., YYYYMMDD). The semantic transformation, on the other hand, deals with the content of the data. Eliminating duplicates, adjusting measures like gallon to litre, or unifying value ranges are some examples for such transformations. Another task at this step is to accumulate additional data, such as detailed information about the involved cars using their serial numbers, etc.

The last step is to load the data from the sources to the data warehouse. Here it is important that during the loading process, which can take a long time for huge data volumes, the source database is not used for transactional operations in order to maintain the integrity of the data. Because there are no real-time applications within the framework this step should, however, not cause problems. The most important thing at this step is to have a well-defined schema and transformation rules to provide maximum quality of the collected data.

4.3 Utilising Data

After data about accidents, traffic conflict situations, and the road and its environment is gathered, this data has been stored twice, in standard databases and in a data warehouse. By doing this, the framework makes the data available in a way that allows one to perform analyses with it and facilitates the use of the data in different ways. On the one hand, the classical procedure of stating a new hypothesis and then validating its correctness by analysing the data becomes easier, while on the other hand, the data warehouse allows applying data mining and knowledge discovery techniques on the data to find unknown facts without having to state a concrete hypothesis.

4.3.1 Facilitating Road Traffic Safety Research

A scientist, researching in the field of road traffic safety has to deal with many problems. After having formulated a hypothesis about road safety relevant relations, the first problem is to gather existing data. The researcher then has to perform the time consuming task of studying and analysing the data, which is often only available in form of unstructured written reports. The framework addresses all of these steps by proposing several systems that will facilitate the research in this field.

Consider a researcher who states the following hypothesis about how watching car racing movies can affect the number of accidents:

“Watching car racing movies affects the driving style and leads to more accidents.”

The data needed by the researcher to prove this hypothesis without using the proposed framework, is not easy to gather, because accident data is often available only in a statistical aggregated form. To find data about the television programs of different TV stations and to filter out car racing movies by genre should be easier. After collected the required data, now the researcher has to manually generate queries in order to compare the number of accidents on days on which car-racing movies had been broadcasted with the number of accidents on days without car racing movies.

Using the proposed framework, however, the researcher would be freed from the difficult task of manually comparing the gathered data. Further, not only is the quantity of accident data higher, but also the quality, because additional information about the accidents, such as involved cars, age of participants, weather etc. are already available within the framework. Then there is not only accident data, but also data about reported conflicts, the number of which should also be increasing, if the hypothesis is right.

To analyse the given hypothesis, the available data in the data warehouse has to be matched against the data about the television program. For this purpose, the researcher has to create a data mart. A data mart is in general an OLAP-cube, containing a subset of the data warehouse, to provide the user with only the data he needs. The only restriction while integrating external data into the data mart is that it has to be in a well-structured digital form that can be processed by the computer.

The data will then be linked together using the date information, so the researcher has only to declare the date format of the external data. The result is an OLAP-cube with the dimensions: accidents, television program, and date. Using the standard operations of OLAP, which we described earlier (e.g., slicing, dicing, etc.), the researcher can now easily analyse if his hypothesis is confirmed by the data or not. He can also generate statistical reports and graphics to demonstrate his results.

The main advantage of the framework here is that much more detailed research can be performed in a shorter period of time. As mentioned before, there is a lot of extra information at the disposal of the researcher, so that he could easily look, for instance, if watching movies from any other genre had an effect on the number of accidents, without having to put any additional effort. Such comprehensive studies can be done either manually, by browsing through the OLAP-cube or automatically. How the framework can analyse the data and acquire knowledge on its own, is described in the next subsection.

4.3.2 Facilitating Knowledge Discovery

With the development of sophisticated computer techniques and the resulting huge amount of available data in many commercial and scientific fields, the search for methods to discover knowledge within this data has begun, because it was no longer considered possible for a human analyser to consider all aspects on his own. Knowledge discovery techniques from databases have been widely used in business for market basket analysis to find cross-selling products, or in scientific research, especially within the field of Bio-informatics, to study human genetics and so forth.

The task of discovering knowledge from existing data is called Data Mining (DM). DM is often defined as "the nontrivial extraction of implicit, previously unknown and potentially useful information from data" [Frawley et al., 1992, p. 3] and as "the science of extracting useful information from large data sets or databases" [Hand et al., 2001, p. 27] The problem with these definitions is, that according to them data mining provides one with information found within the available data, but it does not say anything about its meaning or usefulness and therefore, has still to be understood and interpreted by the analyst.

For that reason use the definition by Bensberg [2001, p. 65] is preferred, who defines DM as an "integrated process, that finds patterns using several methods over a data corpus". The mentioned methods are sophisticated algorithms from the field of pattern recognition. The most common method is the affinity analysis which looks for dependencies in the form of "if a is true, then b is often also true". Examples from the real world would be "if someone buys muesli, he often also buys milk" or "if someone is drunk and drives, then he often has an accident". This method is widely in use, because it can find dependencies where no one would expect them.

Another common method is the cluster analysis. The goal here is the clustering of the data in subsets, so that each subset is homogenous in itself and heterogeneous with the other subsets. This method is often used to analyse customer behaviour and can be applied, for instance, to validate the effects of a certain road design element on road traffic safety.

At this point, the user of the framework has to choose the right method for his purpose and to define the scope of the analysis, because running a method over all the available data without any restrictions, can result in a big number of results with less informative value. In general the user creates a data mart and then runs several algorithms to achieve the best performance. This way the standard procedure of a researcher works changes.

Consider the imaginary fact that sitting on the left side of the car, the driver's visual range in right curves is affected on highways and freeways. This circumstance would lead to more accidents in right curves than in left curves. Within the normal scientific approach the scientist would have to construct this as a hypothesis, then would have to analyse available accident data and find out that there are indeed more accidents in right curves than in left curves a would finally conclude that his hypothesis is right.

Our implemented framework, however, changes this procedure for knowledge discovery. Without any specific hypothesis in mind, the researcher can ask the system for dependency patterns between the road shape and the accidents. The system will then show the researcher identified patterns, including the fact above. Having been presented this fact the duty of the researcher is now to interpret it in order o find the reasons behind it, and to propose countermeasures to correct or improve them.

This change in the approach of knowledge discovery brought about major benefits at the marketing level of business companies as well as in some scientific research fields where data warehouses and data mining techniques are commonly in use. Therefore, we expect similar benefits from our proposed framework in the field of road traffic safety research.

4.3.3 Facilitating Administrative Procedures

The framework is not intended to only gather the information for the purpose of analysis and knowledge discovery. Moreover, it is intended to actively propose measures to be implemented on roads. Because of this involvement in administrative procedures it also covers the tasks of the whole life-cycle of proposing countermeasures according to some rating, monitoring the status of their implementation, and evaluating their effects on road traffic safety.

Rating. As the authorities have to consider several time and budget limitations while selecting the measures to be implemented, the framework has to assist them during their decision by presenting them the best possible measures that satisfy their constraints. The constraints that affect the decision for or against a certain measure are the costs, the required time for its implementation, and the potential level safety enhancement it can bring about.

The costs of a measure can be calculated in advance, whereas the potential benefits can only be estimated. A good reference point to start would be the published results of the European Nation's SUPREME project[14] or the extensive report by Elvik Rune and Truls Vaa, who presented in their book “The Handbook of Road Safety Measures”, the results of their study of road safety measures that cover, among other things, their effects on road safety including their estimated safety potentials as well as their costs.

The system has also to consider the time that is required to implement a measure. After having been given the cost and time constraints, the system has to present the user with an overview of short-term, middle-term, and long-term implementation plans with their expected costs and estimated benefits.

Monitoring. The framework has to provide the means to monitor the progress of the implementation of the selected measures. The system has at least to register which measures were selected, their planned and actual date of implementation, and their planned and actual costs. As it is important to control the quality of the implementations, a system to perform control surveys should be developed and integrated into the management system.

Analysing. After the framework has been fully implemented and used for some time, the collected temporal data about accidents and conflict situations should be sufficient to accurately validate the efficiency of road safety measures. The results of such analysis can then be re-entered into the system to be used at the stage of measure rating, which would gradually increase the accuracy of the proposed measures and subsequently improve road traffic safety.

4.4 Implementation of the Road Traffic Safety Framework

In the previous subsections the internal systems that build up the proposed road traffic safety framework were described. Partially, it was also described how they can be implemented and used. In this section, it is described how the framework as a super ordinate lifecycle should be implemented to yield the best possible performance. **Figure 4-4** shows the detailed architecture of the framework.

[14] http://www.kfv.at/supreme/

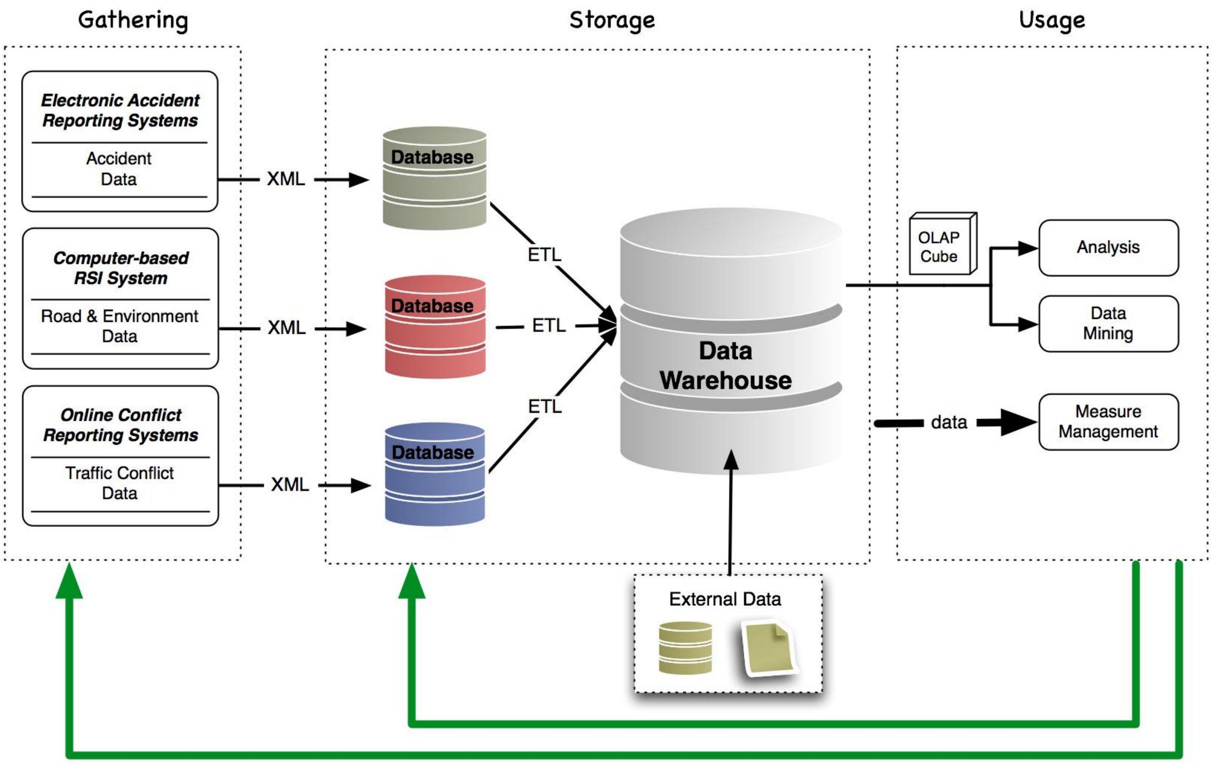


Figure 4-4: Overall architecture of the Road Traffic Safety Framework

The lifecycle begins with the gathering or collecting the three types of data, which is handled by many different institutions where the data is administrated within XML Files. Usually the institutions use their gathered data themselves internally, for instance, the executive forces that uses its registered accident data. However, the original data should not be changed in any way. Therefore it is important that the institutions provide the responsible authority with the data in its original form.

For each data type one separate database is provided. Normally, one database should be sufficient, but it has to be considered that due to the bureaucratic structure several different authorities gather the data. In such a case, either a central database at a higher authority has to be used which collects the data from the several databases, or the data warehouse has to get the data directly from the different databases. Both cases have their advantages and disadvantages, which depend highly on how the data is split. If the databases have the same data structure, a central database is practical. This could be the case when different institutions carry out the RSIs and the results are stored separately. If the data structures of the databases are different, it is more suitable to not use a central database. An example for this case is accident data from the executive forces and the insurance companies.

The data in the databases are then collected into the data warehouse following the ETL-process. Available external data, such as data about road facilities, locations of traffic signs, bikeways, routes of public transportation vehicles, traffic lights, weather information etc. can also be integrated into the data warehouse.

At the last stage, the gathered data is utilised in two different ways. On the one hand, academic and industrial scientists can perform comprehensive studies that can lead to new knowledge. On the other hand, the authorities can use the gathered data to improve the road traffic safety by correcting the detected hazards. The knowledge, gained from the research can either be integrated into the data warehouse, or can affect the basic methods of the first stage and improve the quantity or quality of the gathered data. The administrative actions will generate data, such as data bout fixed hazards or the real costs of measures, which has to be fed back into the corresponding database.

After the framework is developed and fully implemented, the continuous gathering of data will let the data warehouse grow and make more and convincing studies possible. The outcome of the utilisation of the data improves in turn the methods and increases the quality of the framework.

In this chapter the road traffic safety framework was introduced to enhance the whole workflow of assessing and improving road traffic safety using methods from the Computer Sciences. It was pointed out that in the data driven point of view, the most important and qualitative type of data is the data gathered through RSIs. Therefore, computer-aided road safety inspection system was implemented, which is described in the following chapter.

CHAPTER 5

5 Computer-Aided Road Safety Inspection

Road Safety Inspection (RSI) is a relatively new method for detecting road hazards. As seen in Chapter 3, it has a complex nature and is very cost demanding, but provides one with very detailed information about the road design and its elements that are relevant for the road traffic system's safety. Because of the high costs, there is a big gap between the theoretical best practice, where RSIs are performed for the complete road network periodically, and the actual practice, where only sections of the road network with a high safety risk are identified to be analysed with RSI.

In this chapter first a look at current RSI practices in Austria is taken. By doing so the strengths of the actual practices will be outlined, while their limitations and how they could be overcome by using computer-based systems will be the main focus. These limitations will lead to one of the major contributions of this work, which represents a substantial part of the proposed Road Traffic Safety Framework, namely the computer-aided RSI system, **EVES** (Electronic Road Safety Recording System = **E**lektronisches **V**erkehrssicherheits**E**rfassungs-**S**ystem).

5.1 Road Safety Inspection in Austria

The Austrian road network consists of 2.000 km motorways and freeways, and of 35.000 km federal roads. The responsible authority for the motorways and freeways is the Austrian Highway Operator, ASFINAG[15]. The 80.000 km of the urban road network are under the responsibility of local provincial governments, who conducted only a few experimental RSIs on some parts of the road network without a standard methodology HLEM, 2006.

The first RSI in Austria was performed in 2003 within the scope of a pilot project, carried out by the Austrian Roads Safety Board (Kuratorium für Verkehrssicherheit – KfV)[16]. The RSI covered ten inspections on a total of 150 km of highways. During these first inspections, the road-engineering bureau Nast Consulting[17] developed a standardised approach to RSI by defining a checklist of safety deficiencies to look for during the inspection [Lutschounig et al., 2005, p. 6].

Till the year 2006, 270 kilometres of the highway road network were analysed using RSI [Elvik et al., 2006, p. 3]. The current state (in the year 2008) shows that inspections have been performed for about 700 km of the highway road network. The cost of an RSI is estimated as 10.000€ per 10km, while this amount only covers the costs of the inspections and not the costs for implementing the suggested countermeasures [Lutschounig et al., 2005, p. 6].
Currently, only ASFINAG considers RSIs as regular part for road network maintenance. They identify hazardous road sections by analysing accident rates and tender contracts for the RSIs. In Austria, only a few engineering bureaus have the required knowledge and expertise to undertake a RSI Nast, 2006. Once the contract has been let, the planning phase begins. First, an accident map of the identified sections is constructed in collaboration with the KfV, which is gathering the accident data in Austria. In the next step dates are fixed and appointments are made. Usually, a RSI ought to be performed at daylight and clear weather except it is a special inspection with the objective of detecting hazards at night, by rain, or snow.

In addition to the experts who are carrying out the inspection, a motorway foreman is also involved in the process of a RSI. Because the motorway foreman is the one with the most valuable and accurate non-statistical information about the road, a short briefing before the inspection is very helpful. If possible, he should also be present during the inspection itself to answer upcoming questions or to comment on certain situations or places on the road.

A major problem during the inspection is the speed at which the car has to be driven to not affect traffic safety. This makes it very difficult to write down the detected risk factors or note

[15] http://www.asfinag.at
[16] http://www.kfv.at
[17] http://www.nast.at

down some additional information. Currently, this problem has been overcome by recording the whole survey on video and to speak the additional information on tape. This enables the experts to concentrate on the road and on detecting possible risk factors. An additional benefit is, that the video may capture details that were overseen by the experts during the survey so that they can later be discovered during post-processing in the office.

The things that have to be registered during the surveys are numerous and therefore make it sometimes necessary to drive through some sections more than once. Table 5-1 depicts the checklist for RSI of motorways in Austria.

After the survey, the post-processing phase in the office begins, which is very time-consuming, because the expert has to watch the videotape several times over and to write down the registered events. For each event, the deficiencies it may lead to have to be defined and countermeasures to be suggested. Every risk factor of an event has to be declared as a low, medium, or high risk factor. Further, it has to be decided, whether the proposed countermeasure should be implemented in short-term, middle-term, or long-term. As there are no defined standards to make these classifications, the expert has to decide on his own Nast, 2006. For instance, cutting of sight-hindering vegetation is a countermeasure that can be taken in short-term, whereas the redesign of an insecure exit ramp needs physical redevelopment and is therefore a long-term countermeasure.

The local assignment of the registered hazards is done using the road kilometres. On motorways, for instance, there is a kilometre sign every 500 meters. So one has to estimate the location of a hazard based on the distance to the previous and the next sign, which leads to an imprecision within the scale of 100 meters. This may be considered acceptable at the detection phase, but can cause problems once the implementation of the countermeasures has to be controlled. For example, if a road sign was not well visible and a countermeasure was stated to relocate it 100 meters ahead, one could hardly tell during the control survey, whether the sign is on his designated place or on his original place.

Usually, the results of the inspection are manually compiled in form of a report to be handed to the ordering party. A report contains the list of all detected events, a screenshot of their spot taken from the video footage, their safety deficiencies, and suggested countermeasures. This unstructured form the collected data is saved, makes it very difficult, if not impossible, to utilise it for further analyses. Further, there is currently no control mechanism to track the status of the suggested countermeasures and their effect, as well as no legal requirement to fix the reported events.

With our computer-aided RSI system, which we describe in the remainder of this chapter, we aim to facilitate these time-consuming parts of current RSI practices.

A 8 - Innkreisautobahn	Relevance for safety			Road safety analysis	Measures
	High	Mid	Low		
Highway design parameters	**x**				
Design in general			x		
Alignment		x		Radius of transition curve too small	
Cross section, including shoulders	x			Narrow shoulders as a result of maintenance work, drainage problems, etc.	Broader shoulders and transverse grooves to improve drainage
Sight conditions	x			Restricted sight, in particular in curves to the right	Provision of adequate sight distances
Service areas	x			Unsafe exit from parking space at km 21	Upgrading the exit area
Entry ramps		x		Small curve radius and too short sight distances	
Pavement condition		**x**		Km 19,0 - km 19,5: poor road surface condition	
Analysis of traffic operations	**x**				
Speed	x			Not measured	More enforcement and variable speed limits
Traffic volume		x		AADT: 23.600	
Heavy vehicle volume	x			AADT: 7.200 (31%)	
Light conditions		**x**			
Dazzle from sun			x	Not a problem	
Dazzle at night		x		Possibly a problem	Anti dazzle screen on median guard rail
Surrounding lights			x	Not relevant	
Road lighting				Not relevant	
Traffic control devices			**x**		
Traffic signs			x	Not a problem	
Destination signs		x		Parking space not properly signed	Upgrade signing
Road markings			x	Unimportant	
Plants			x	Unimportant	
Elements in the dark			x	Unimportant	
Directional devices			x	Unimportant	
Weather management		**x**			
Rain		x		46% of accidents on wet road surface	Speed is reduced during rain
Snow/ice			x	Unimportant	
Fog		x		Does not occur frequently	Attention to spots where fog may form
Surroundings of road			**x**		
Houses			x	Unimportant	
Information facilities			x	Unimportant	
Trees, bushes			x	Unimportant	

Table 5-1: Checklist used in RSI of motorway in Austria **[Elvik, 2006**, p. 4]

5.2 EVES A Computer-aided Road Safety Inspection System

We already mentioned that since the start of pilot road safety inspections in Austria in 2003, Nast Consulting has been in close cooperation with the responsible authority, ASFINAG, and has carried out most of the road safety inspections on the motorways in Austria. Over the years it became clear what the limitations of their existing methods were and how a computer aided procedure could ease and facilitate road safety inspections to be performed more systematically. Driven by this idea, Nast Consulting, worked on a project proposal for the development of such a computer-aided system, which has been funded by the Centre for Innovation and Technology (Zentrum für Innovation und Technoglogie – ZIT)[18]. The application fields of the system were considered in two groups, depending on the devices on which the system was supposed to run. For the higher road network, where the inspection is performed in a driving car, the system has to run on a notebook computer. For the lower road network (e.g., bikeways, footpaths, etc.), however, where the inspection is performed on a bike or on foot, the system has to run on a mobile device.

Nast Consulting worked out the functional requirements specification, where the focus was mainly on improving the time consuming parts of the current practices. Accordingly, the required computer system had to be able to

- easily register safety relevant events during the inspection,
- automatically locate the gathered events using GPS
- provide the user with a clear user interface to give an overview of the registered events on the map
- facilitate post-processing of the registered events by providing editing means and video synchronization
- facilitate reporting by automatically generating reports according to pre-defined structures

The implementation of the system that reconciles these requirements was undertaken by the author of this thesis as a substantial part of the proposed road traffic safety framework. In the following the architecture and functionalities of the resulted software, which has been named EVES, are explained.

Before starting with the description of EVES, the meanings of some terms used through the rest of this chapter should be clarified.

[18] http://www.zit.co.at/

- **Event**: is a general term describing everything that is registered during the inspection related to the road traffic system's safety. We do not use the term hazard, as the system can also be used to capture other things than hazards, such as the number of lanes, etc.
- **Project**: comprises the entirety of all tasks related to one inspection on a specified area.
- **Road**: stands for a real road of the road network.
- **Route**: stands for of one or more road sections, describing the part of the road network that is going to be inspected in the scope of the project.
- **Survey**: describes the actual inspection of a passage of the route. In general, at least two surveys are carried out for each project, that is, one survey for each direction of the specified route of the project.

In order to give the reader a good overview of the software's functionalities and features, especially those that optimise previous approaches, EVES is explained by considering every step of the inspection workflow: preparations, survey, post-processing, and reporting.

5.2.1 Using EVES to Define the Data Structures

As mentioned earlier, it is important to have a well-defined checklist of events that are going to be detected during the survey. This way it is ensured that important events are not overseen and the survey has not to be repeated.

Let us assume that one wants to use EVES to detect and register events regarding safety hazards on motorways. Let us further assume that one does not want only the information that a hazard exists, but also additional information, such as its state and what its shortcoming is. The state "overgrown" of an event "vegetation", for instance, could have shortcomings, such as "causing poor visibility", or "risk of limbs falling on the road". For each shortcoming one could define at least one countermeasure to eliminate the shortcoming or its effects.

In order to tell the system what kind of information should be registered for each of the detected events, one has to define its structure to which is referred as its *Event Type*. For our scenario, one could define an Event Type called "Motorway" with the data structure as depicted in Figure 5.1.

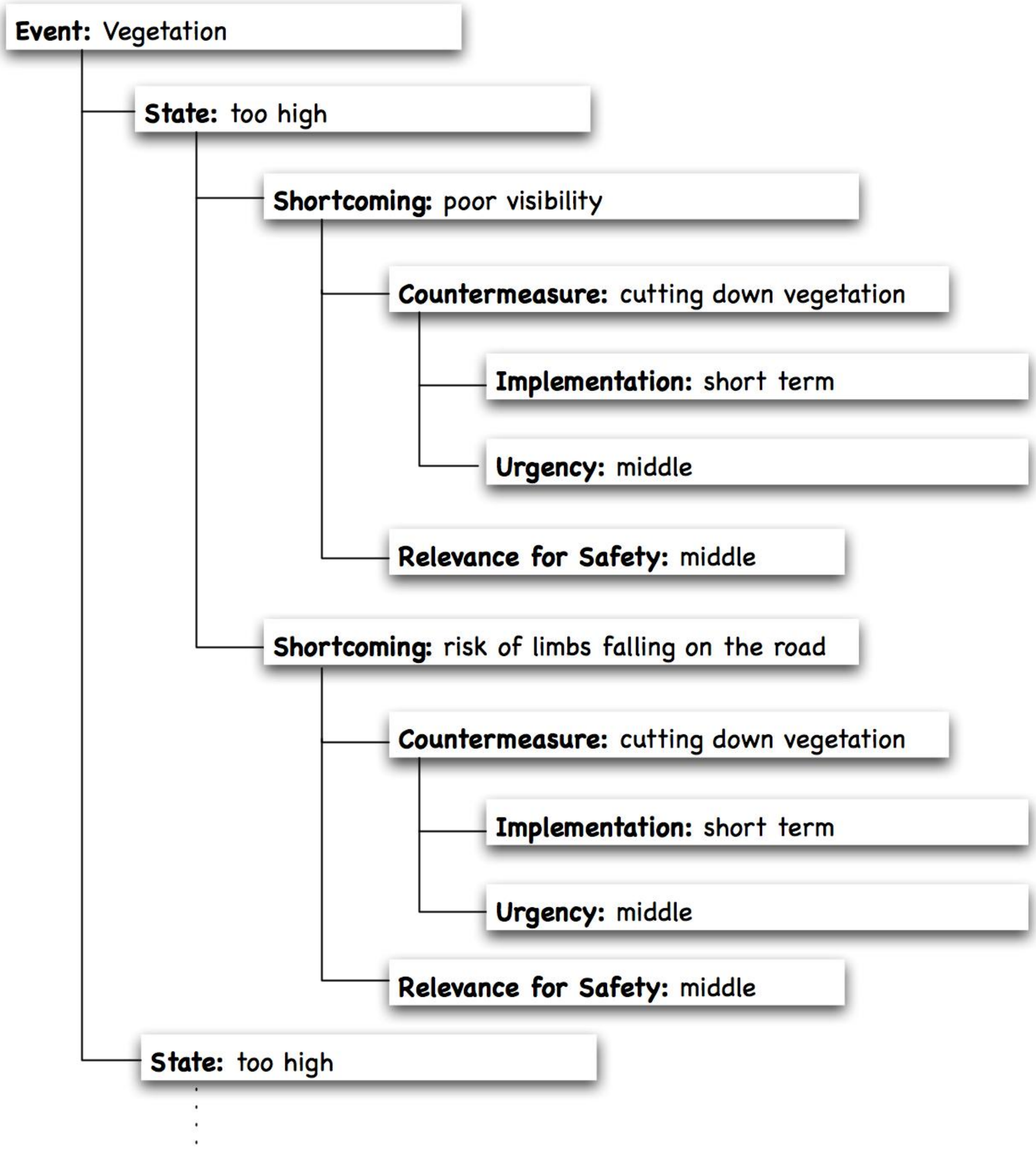


Figure 5-1: Data structure of a sample Event Type „Motorway“

It is clear that the desired data structure (i.e., events and their attributes) could differ from application field to application field. In order to enable EVES to be used for all road and inspection types, one of the main objectives during the development of EVES was to provide utmost flexibility. This objective resulted in the development of several tools within EVES that provide the user with means to easily adapt and use the system for different purposes. In the following the three structural managers that give the user full control over the underlying data structure are described: the Event Type Manager, the Category Manager, and the Module Manager.

Event Type Manager. The *Event Type Manager* allows the user to define Event Types for different purposes. Figure 5-2 shows the data structure of our "Motorway" Event Type as in the above mentioned example.

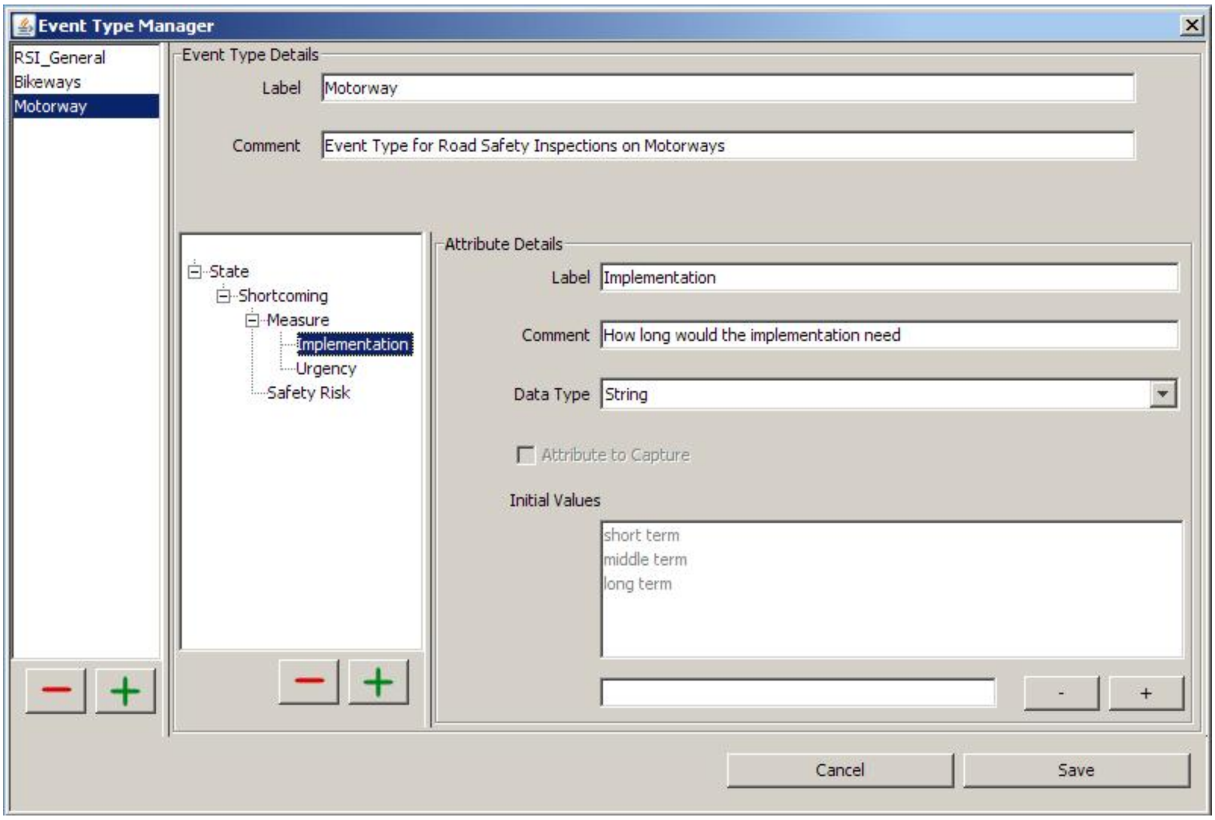


Figure 5-2: Our sample data structure as defined in the Event Type Manager

With this interface the user can define the data structure of an Event Type, by adding attributes where needed. It allows the user to define several Event Types for different purposes and hence provides a flexible system for handling events from different application fields or survey types (e.g., Bikeways, etc.).

Category Manager. After having defined the desired Event Types according to which the user wants to capture events during the survey, he has to enter the events in the checklist into the system. This task is performed using the *Category Manager*. Theoretically, the user could define all the events without defining a single category. However, as the checklists for RSIs are in general very long, the maintenance of such a list would soon get uncomfortable. In order to provide a thematic summarisation of the events, the user has been given the possibility to define hierarchies of categories and to add events wherever desired. Figure 5-3 shows the user interface to perform these tasks:

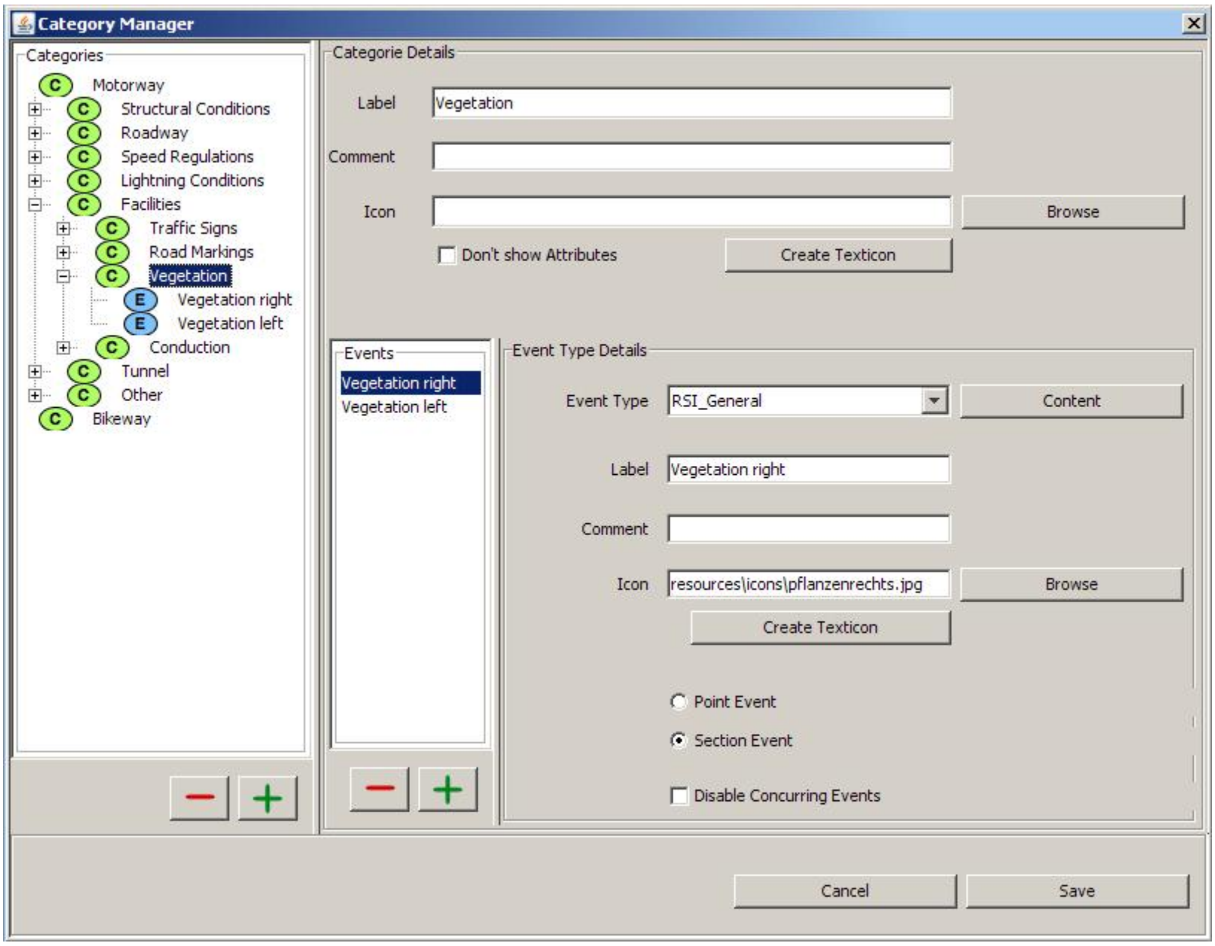


Figure 5-3: Sample category structure as defined in the Category Manager

With this interface the user can define the needed categories, where the user can also assign icons for the events to be used during the survey. It is also important to declare whether an Event is a *Point Event*, indicating an event at a certain point of the road (e.g., bad positioned traffic sign) or a *Section Event*, indicating an event that lasts along a certain section of the road (e.g., a missing service lane). Further, the user can state whether more than one instance of an event can be registered during the survey at the same time. Let us take the events in the "Speed Regulations" category as example. It is not possible to have more than one instance of this event on a motorway at the same time, because a speed limit sign overrides the previous speed limit (e.g., 70 km/h sign overrides the previous 100 km/h sign).

Through this interface the user gets access to the *Event Content Manager*, where he actually enters the content of the events, that is, its attributes (see Figure 5-4). The more detailed this work is done, the easier and faster the post-processing and the reporting will be.

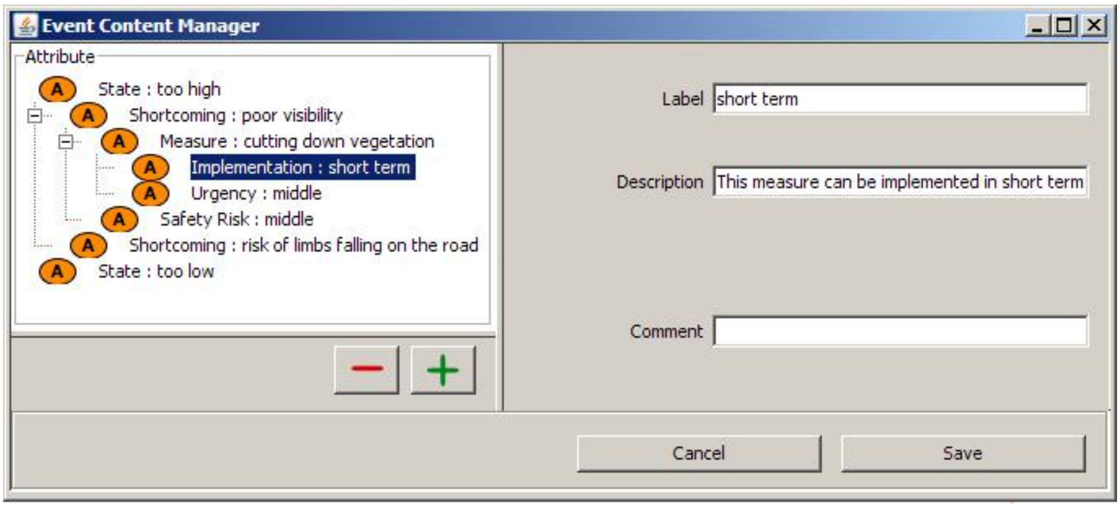


Figure 5-4: Sample event content as defined in the Event Content Manager

Module Manager. Another structural manager that EVES offers to provide maximum flexibility is the *Module Manager* (see Figure 5-5). A module is a collection of events and categories that are relevant for a certain sort of inspection. The Module Manager allows the user to define separate modules for motorways, highways, rural streets, construction sites, or for inspections for night-time, different weather conditions, etc. For each module the user composes a graphical board that contains the icons of the events and categories of this module.

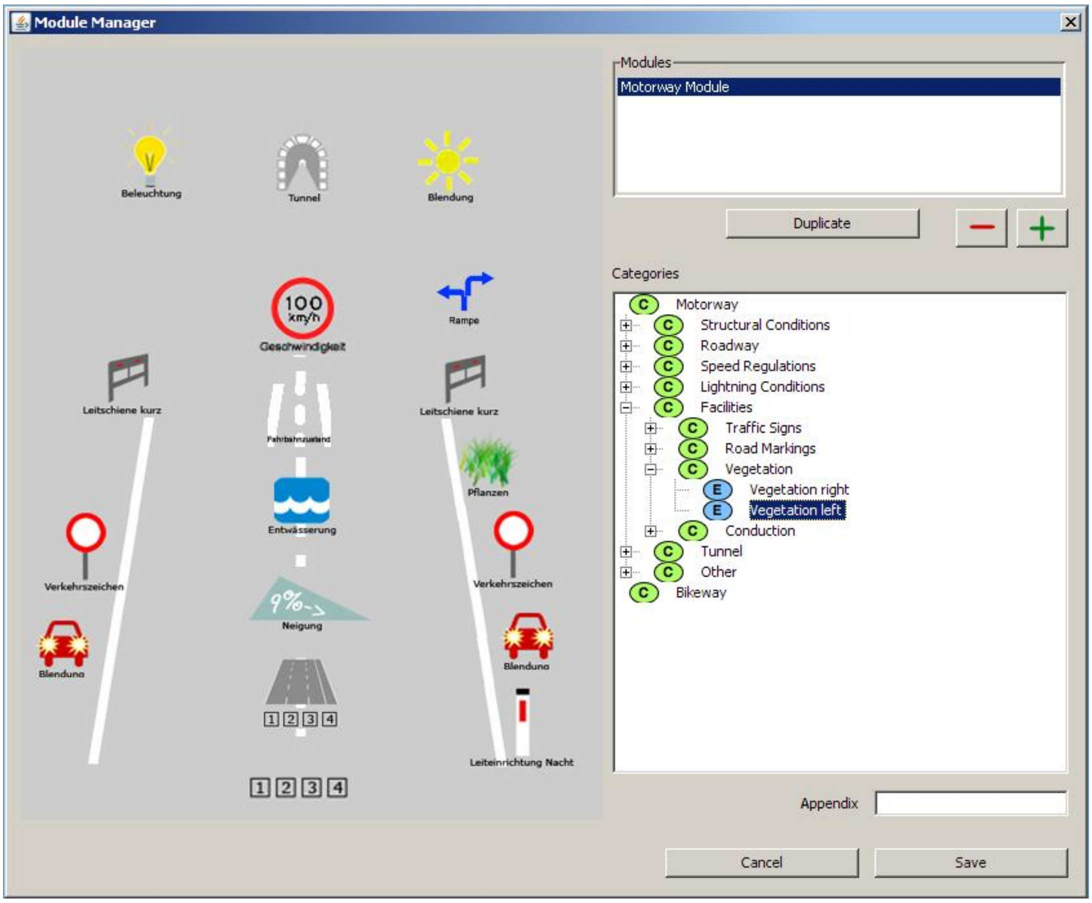


Figure 5-5: Sample module for our example as defined in the Module Manager

After the data structures have been set, the user can begin to prepare for the survey. Note that the steps explained so far are the steps that have to be undertaken only once after the installation of EVES and occasionally when EVES is going to be used for different tasks.

5.2.2 Using EVES for the Preparation of Inspections

The first thing to do before carrying out a survey is to create a project for the inspection. Besides general information about client, the person in charge, route to be inspected etc. the user has to select the modules he wants to use for inspection and, optionally, to load the map of the area where the inspection will take place. The current position of the user is displayed during the survey. However, the main function of the map is to integrate and highlight so called *Points of Interest* (POIs) (see Figure 5-6), which are basically predefined spots on the road that the user wants to be reminded of during the survey, such as black spots already identified by other authorities or the user's own POIs, which can be automatically imported into the system using GPS information. The system gives an acoustic signal with an optional written explanation when a POI is approached and is as close as 100 metres.

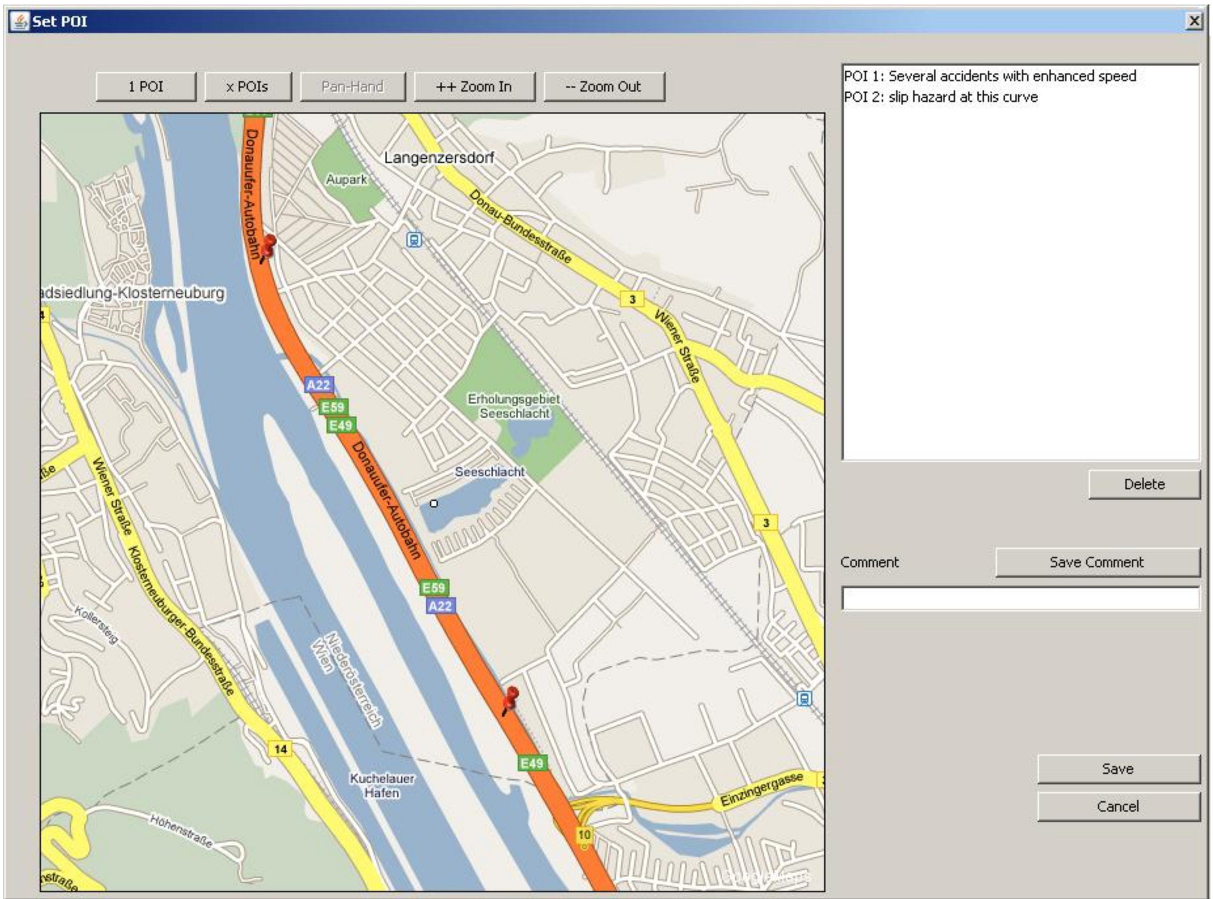


Figure 5-6: Point of interests pinned on the map

The system is build for two-way roads, where for each direction a separate survey is conducted. On one-way roads the second direction can be ignored. For each direction more than one survey can be performed and the captured events can afterwards be merged into one single survey.

5.2.3 Using EVES for Road Safety Inspections

The road survey with the traditional approach is a time consuming and therefore expensive task. Therefore, the main motivation to develop a computer-aided RSI system has been to assist road inspection engineers in every possible way to ease and speed-up the process, hence reducing costs.

There are many ways of presenting the user the predefined events for him to register when detected. The first user design element thought of was the “outlook menu” to represent predefined categories, where clicking on the item would open up the menu revealing its content, that is events and other subcategories. However, after conducted a few test runs with this design, it was concluded that outlook menus are not convenient to use, because the user has to read the labels of the hazards and subcategories to find his way through the menu structure to the correct event he detected on the road and wants to register into the system, which is time consuming and therefore not appropriate to be used during the inspection where the car is moving fast and the engineer has to pay attention to the road in order not to miss other events.

For the second attempt, numerical codes were used for categories and events, with the limitation of maximal three subcategory levels and nine elements at each level. This way each event has been given a unique four-digit numerical code to be identified with during the survey. The main objections against this method have been the loss of flexibility as a result of the stated limitations regarding the structuring and numbering and the required training to memorise the codes before the survey. Even allowing voice commands for predefined event names or numerical codes demonstrated not applicable during a real survey.

All these attempts lead to the conviction that a well-defined graphical user interface with context menus and icons for events or event categories is the most appropriate way.

The main goal during the survey is to allow a quick interaction of the road inspection engineer with the system, so that he can still concentrate on the road. With the introduced graphical modules this goal is achieved as the main module board contains only the most needed elements. It is also possible to record an audio memo for the last registered event with an easy key stroke, so the time the engineer has to look on the screen is minimised, which in turn maximises the time he can concentrate on the road to detect events.

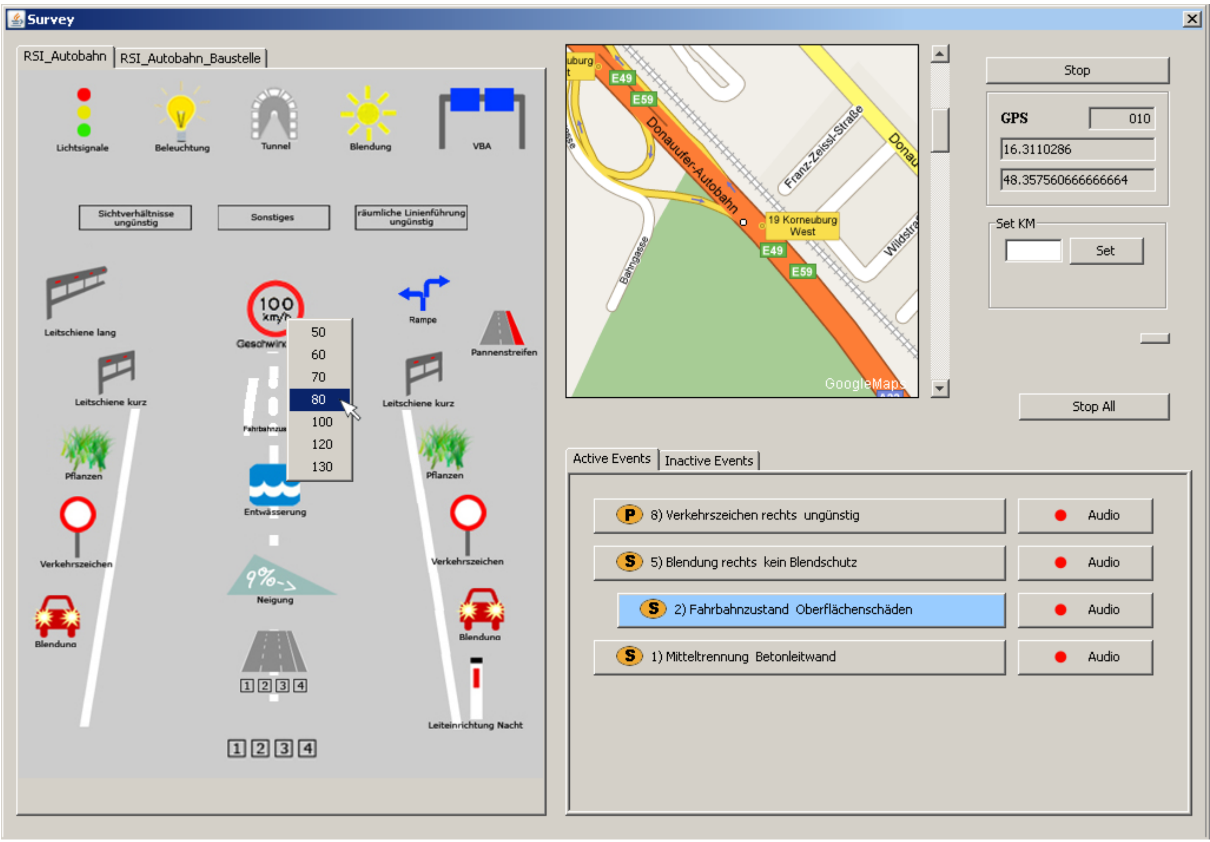


Figure 5-7: Screenshot of the graphical user interface of EVES during an inspection

Figure 5-7 shows the graphical user interface for the survey task. The area on the right side contains the map and GPS data, only for information purposes, and more importantly the list of already registered events. Whenever an event is registered, its label appears in the tab “Active Events”. If it has been defined as point event, it is moved to the tab “Inactive Events” after a specified time, which gives the engineer enough time to record audio memos if necessary. If it has been defined as a section event, however, it remains in the tab for active events till the user indicates its end by simply clicking on the event's label, which assigns the event with the endpoint of the section and moves it to the tab for inactive events. It is further possible to record more than one audio memo for events, no matter if active or inactive, by either clicking on the record button beside the event's label or entering a key shortcut.

Once the end of an inspection for a certain section is reached, the survey can be saved and closed and a new survey on the same section in both directions can be started. As mentioned before, it can be necessary sometimes to drive through a section more than once, especially if the checklist contains too many events so the road engineer is overstrained. The events that are registered in different surveys can later be merged during post-processing.

5.2.4 Using EVES for Post-processing

After the inspection task itself, post-processing is the second important task of a RSI, which is very time consuming if undertaken with traditional state-of-the-art methods. Therefore, one of the main motivations to develop EVES has been to address this problem. Providing a computer-aided RSI system and consequently having registered the data in an electronic and structural form already brings about a great benefit compared to traditional methods, where the survey is usually being recorded on video tape and has to be watched through in order to enter the information into the computer. However, EVES provides further features to ease the task of controlling and editing the registered information if necessary.

Preparations before post-processing. Having finished the survey, there is some optional work to do before starting with the actual post-processing. First, if the map of the inspected area was not downloaded before, it should be downloaded at this point. Even though the map is still not an obligatory element, it is very useful during the post-processing and the reporting afterwards, because it gives the user a good visual overview of the location of the events.

The second preparation task concerns the visual data recorded on videotape during the survey. In general, one tape is used for the whole inspection, so there can be several surveys on one tape. Therefore the video has first to be converted into a digital format and has to be cut and assigned to its respective part of the survey.

Another preparation task concerns the correction of the inspected road course. Because GPS signals have a known inaccuracy of about 15 metres, the registered course can lay several meters aside the real course of the road. If the user has digital road data from a supplier, like Teleatlas[19], in form of a geospatial database, EVES can map the registered course to the real course automatically. Because some parallel roads lie very close to each other, the error in the GPS accuracy can lead to incorrect road selections during the mapping process. In such cases the user can tune the mapping by adjusting the search radius (see Figure 5-8).

[19] http://www.teleatlas.com/

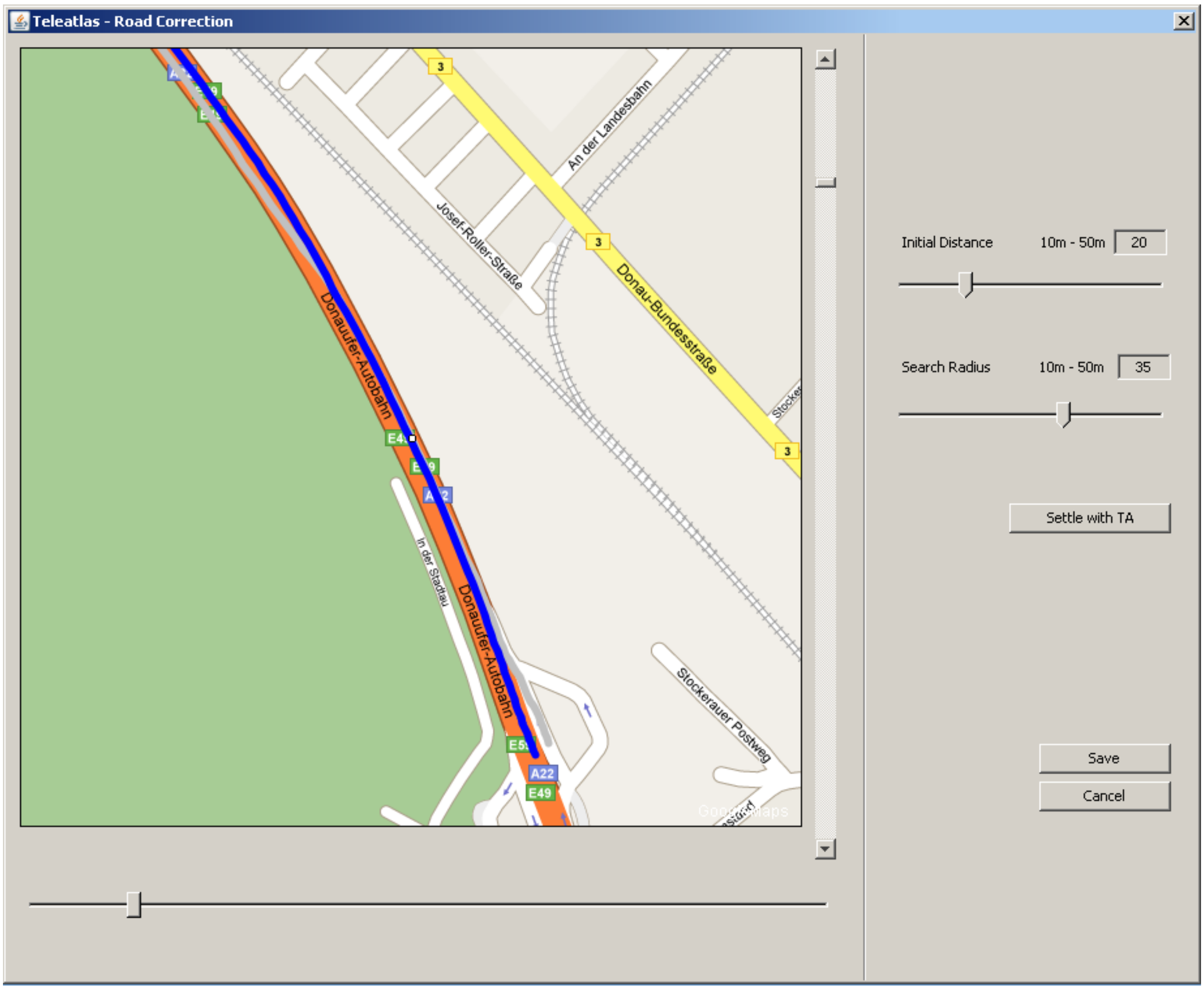


Figure 5-8: User interface for course correction

The last preparation task concerns computing the kilometre information of the roads, which is especially important for freeways and highways, where no address information exists. For that purpose, the user only has to select one of the registered kilometre points during the survey. If no kilometre point was registered, he can enter a new one and determine its location using the map. If the survey covered the inspection of more than one road, a separate kilometre point has to be set for each road, as each road has its own kilometre mileage.

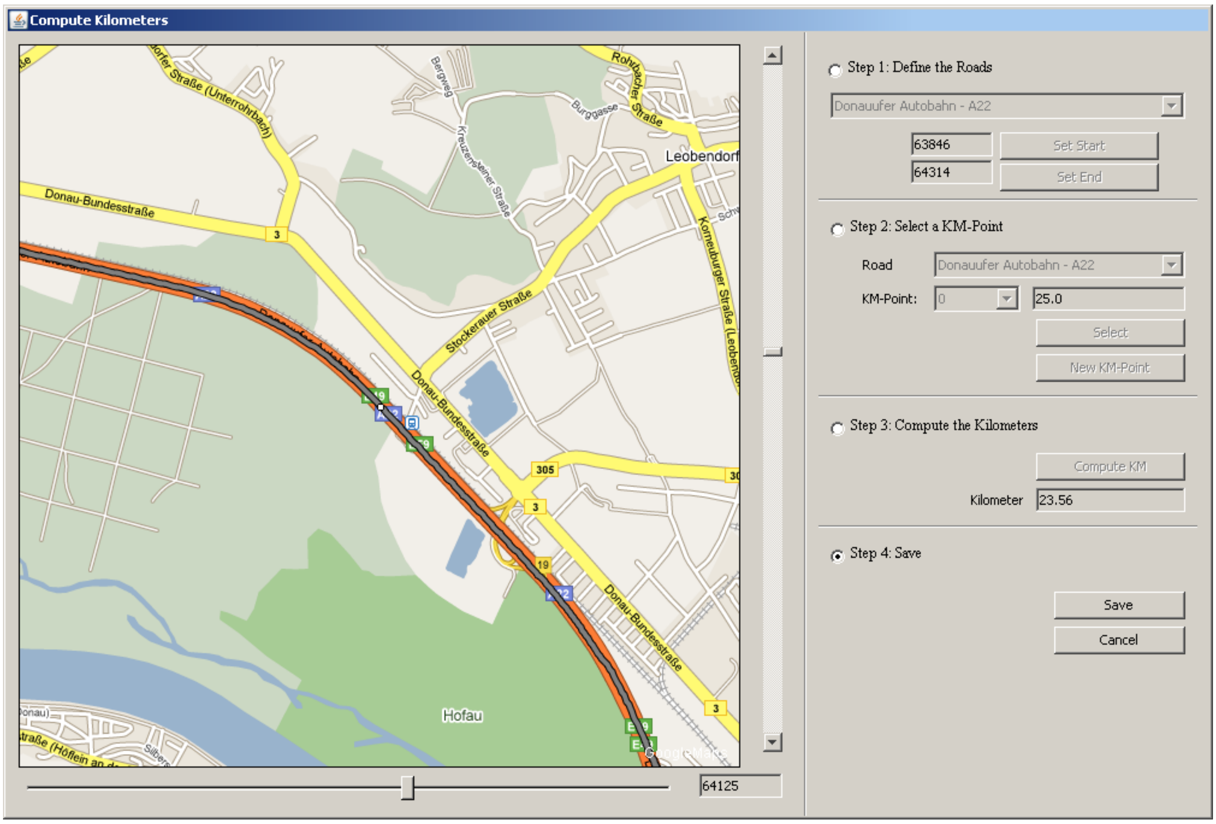


Figure 5-9: User interface to compute the kilometre points of all registered GPS points

Post-processing. The use of GPS enables a precision of about 15 metres for the positioning of events on the road. This is far better than the estimation of the location with the aid of the kilometre signs at every 500 metres on the road recorded on videotape. However, during the survey it is sometimes hard to register the event at the right moment, where a delay of 1 second can lead to a difference of 25 metres from the actual location of the event. Therefore, the user has been given the possibility to correct the location of the events during post-processing (see Figure 5-10).

The attributes of each registered event can be edited as well. For our sample Event Type “Motorway” the user can at this point, select a pre-defined shortcoming of a captured event and select a pre-defined countermeasure for the shortcoming. During post-processing it becomes clear how important it is to invest enough time for the definition of the underlying data structure, because once done it is going to be used over and over again during post-processing and can save a lot of time.

During post-processing the user has further to set the risk factor of each registered event. It is deliberately not allowed to pre-define the risk factor of an event, as the same event may not induce the same grade of risk everywhere it is observed and often depends on several factors. An unguarded traffic sign on a section with a speed limit of 130 km/h, for instance, is much more dangerous than on a section with a speed limit of 60 km/h. The idea of setting default values that could be changed by the user if necessary, was rejected to prevent cases where the user forgets about it or neglects it, which would affect the safety evaluations of the road.

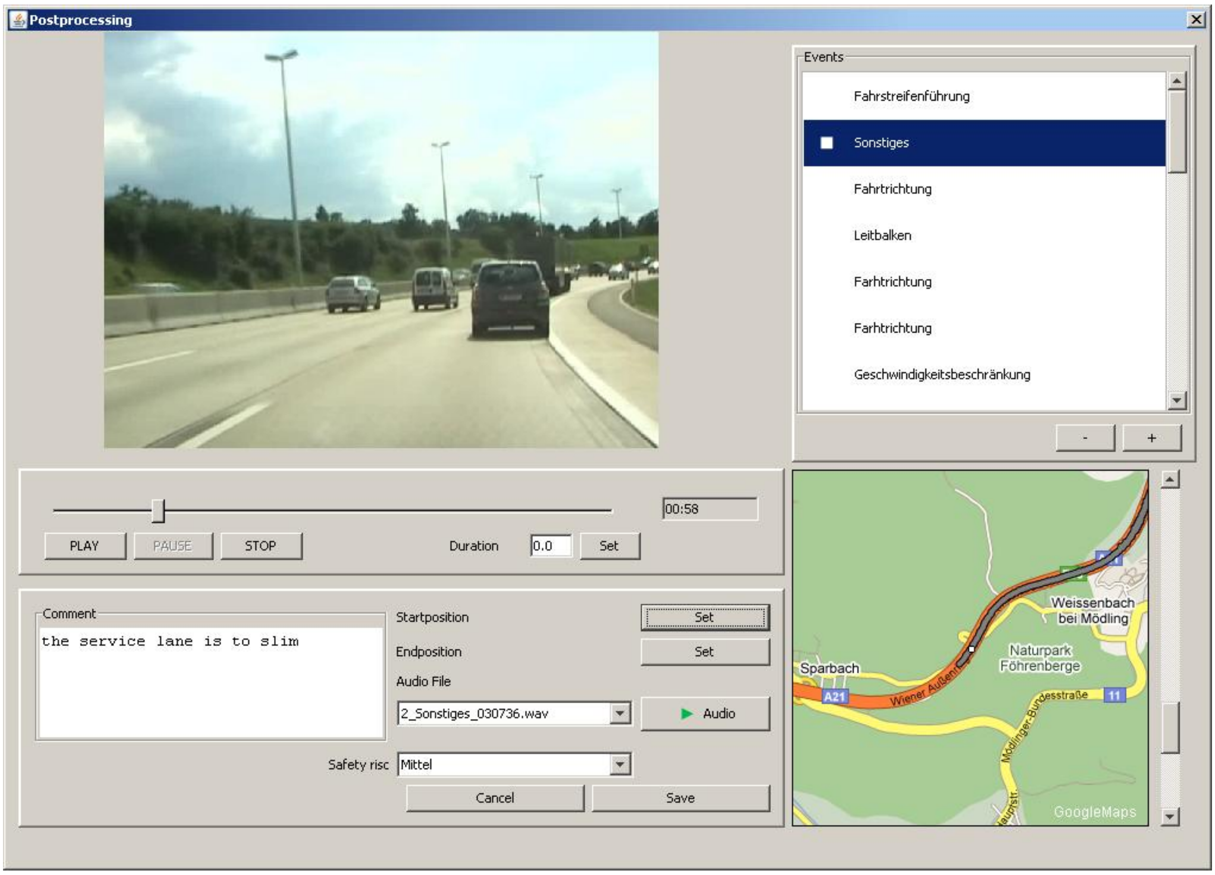


Figure 5-10: User interface for post-processing

5.3 Reporting

Reports of RSIs are very important as they represent summarisations of the inspections to be presented to several authorities. Because the data is not gathered electronically with traditional methods, the information that has been extracted manually from the collected data is put together in form of written reports. To eliminate several disadvantages of this traditional approach, such as the loss of data or the time that is needed to write the reports and fill out the forms, EVES is equipped with a reporting tool.

Without EVES's reporting tool, the registered data could only be used by EVES itself. The dynamic structure of the event types requires the possibility for the user to define which attributes from which events should be written where in the reports, whether he wants to have screenshots from the video, photographs or map to show the location of an event, etc.

This step has big time-saving potential, as a report can be constructed with a few clicks compared with the traditional manual process of entering each single event, taking screenshots from the video, and marking the events on a map. The constructed report is in the

Word format, hence, human readable, but not suited for further processing with the computer. In order to provide the generation of files that can be further processed, the system has to be able to export its data as well. This is done by generating text files in the so called Comma Separated Values (CSV) format, where each line contains elements of a data record (e.g., attributes of a single event) separated with a defined character, usually a semicolon. Such files are very common and can be processed with standard software like Excel.

5.3.1 Using EVES to Monitor the Status of RSIs

The term monitoring covers the work that is done to check the status of a project after inspection, that is, whether the suggested countermeasures have been implemented yet and if they are sufficient. Even though there is not yet a legal basis and therefore no obligation for monitoring, the information about the progress is important in order to evaluate the effects of events and their countermeasures.

One idea that came up during the development of our proposed framework was to integrate the monitoring process into the RSI, as they have to be carried out periodically anyway. This idea however, was soon rejected because of the argument that the road engineer has to look for existing events during the inspection and it would distract him to check the status of previous registered events. Another argument against this idea was that the scheduling of the monitoring is part of the maintenance, so that waiting till the next RSI would hinder the work of the authorities.

Therefore, we extended EVES to allow also the handling of so called *Control Surveys*. The workflow of a control survey is similar to a normal inspection, but much more simple. A control survey is performed on an existing project, so most of the preparation process is not necessary. The user only has to select a list of the previously registered events he wants to control.

The actual survey is a little bit different from the initial inspection survey. Because now he has a list of selected events and drives through same route, the events become activated automatically when they are approached and the distance is smaller than a predefined threshold. This alerts the user and informs him to what to look for next. He can then classify the state of the event as fixed, partially fixed, or not fixed. Back in the office, he can later generate reports of the control survey, either a written report in form of a list of the events and the status of their countermeasure implementation, or a CSV file for the case that any third party software wants to use the results of the monitoring.

5.3.2 Using EVES to Perform Analyses

Comprehensive methods and tools for analysing the gathered data are considered to be developed and integrated into the proposed framework. However, EVES allows the user to perform simple analyses on the gathered data as well. The first tool (see Figure 5-11) allows the user to query all registered events and evaluated sections from all the performed inspections so far by road type, road name, client, person in charge, and events.

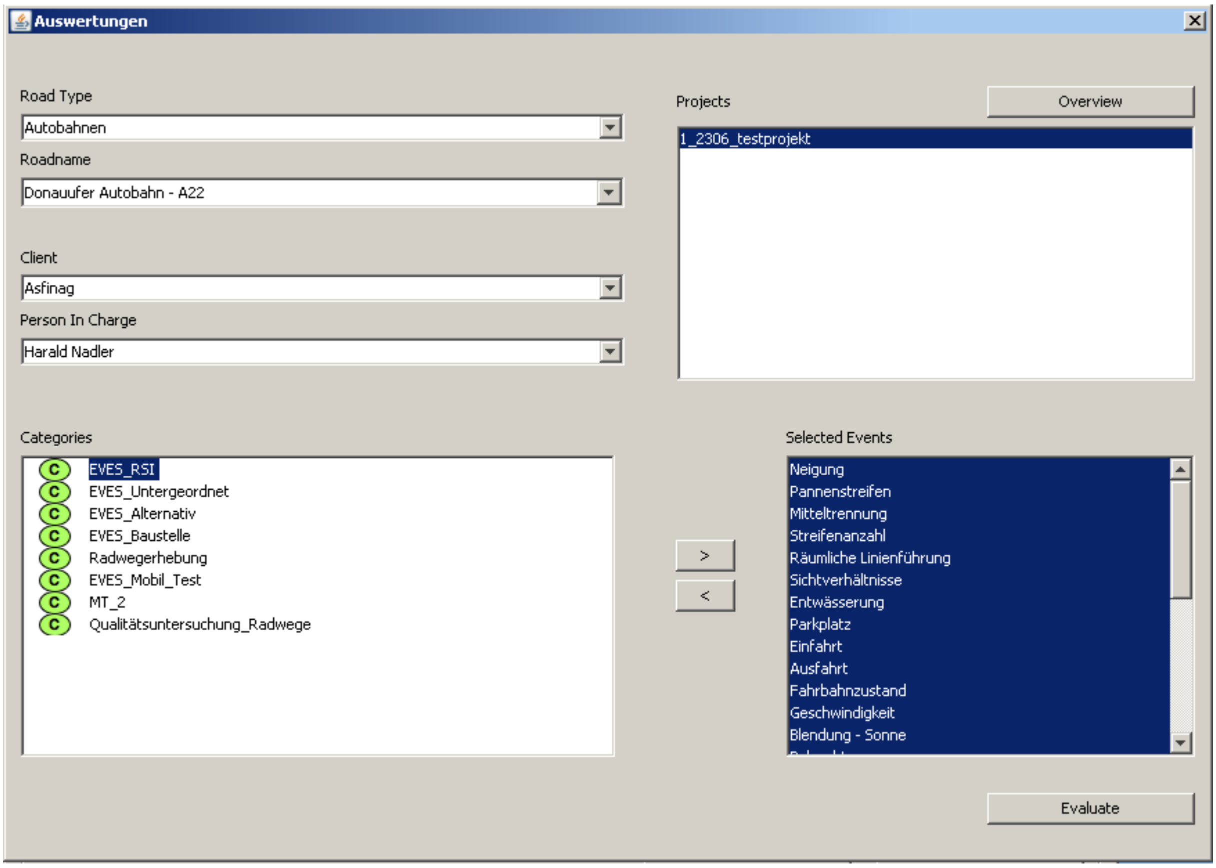


Figure 5-11: Analysis tool to query registered events

The user can then view the results for the resulting sections and events separately and can also filter them (see Figure 5-12). The evaluated sections can be filtered by their safety class (i.e., low, middle, or high), whereas the events can be filtered by their safety risk (i.e., low, middle, or high) or their being point events or section events. It is further possible to export the results of the filtering into a CSV file for later use.

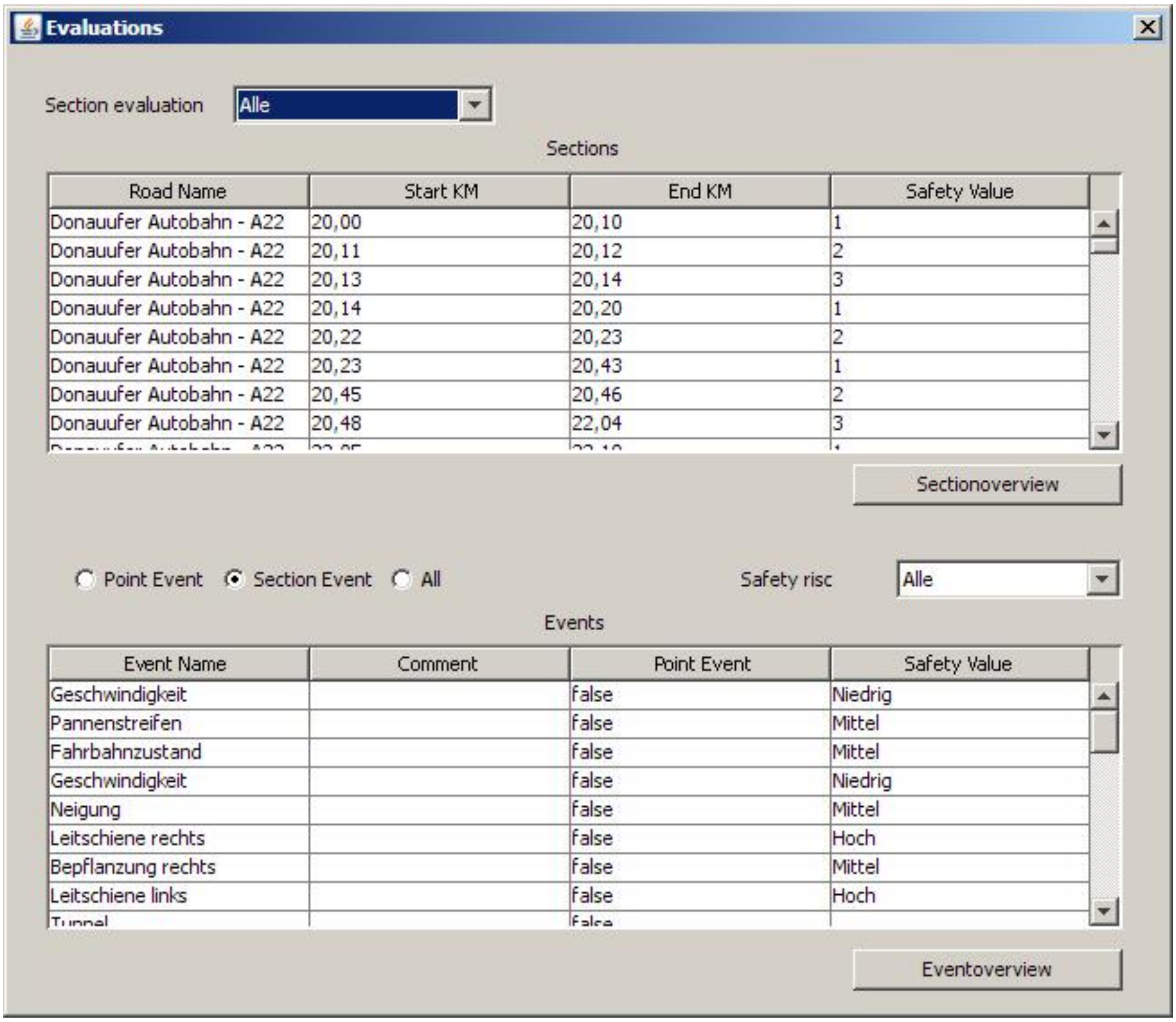


Figure 5-12: Evaluation results of a sample query

The second tool is for rating the safety of a road section from an inspection. The rating score is computed using the defined safety value of the registered events. The method assumes that an event's effect on road safety is not limited to the actual point or section where it is located, but that it also affects the road section before it, decreasing with the increasing distance. That means that an event with a high safety risk at one point or section is also responsible for a safety risk before the point or section, although somewhat lower. The descending intensity of the risk is modelled as a Gaussian function, known as normal distribution in Statistics.

To compute the distribution of the safety risk, two values are necessary: the initial value that marks the highest point of the function and the spreading distance that describes for how long the event influences the road. For each of the three pre-defined safety risk values of low, middle and high, the expert can adjust these two values. This adjusting of course affects the result of the rating directly, but it is necessary, because there are no approved values for different road types. Figure 5-13 shows the interface where the user can make the adjustments and can see the rating of the road immediately.

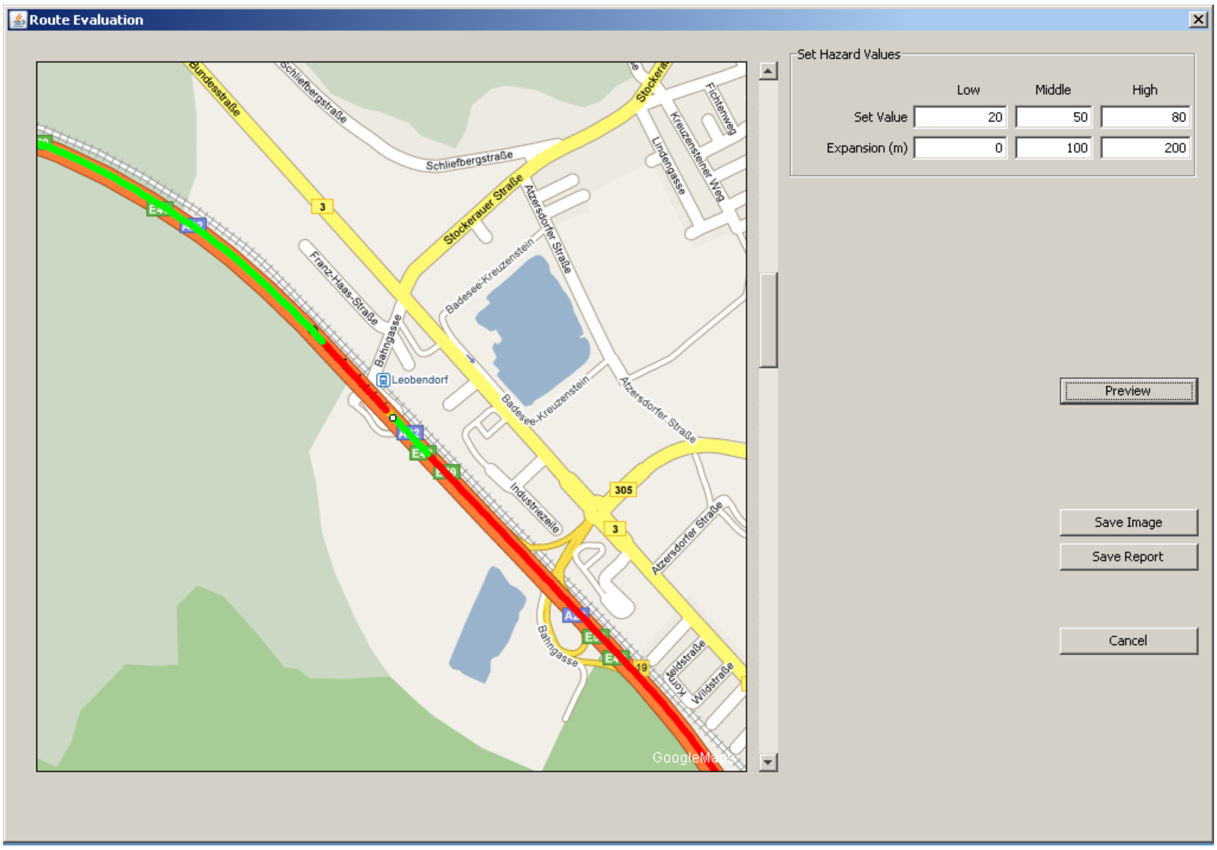


Figure 5-13: User interface to perform adjustments for evalution

5.4 Evaluating EVES

There are many ways to evaluate a software system and we decided to use the feedback method, in order to identify the strengths, the weaknesses, and the limitations of EVES. For that purpose we constructed a questionnaire consisting of questions to evaluate several aspects of the functionalities that EVES provides. The questions were presented to and have been answered by road engineers at Nast Consulting[20], who had the opportunity to thoroughly use the system to perform real RSIs on several roads and therefore, are considered qualified to evaluate it. In the following we present the results of our questionnaire and analyse the results to draw conclusions for further development.

The questionnaire is structured in a way that each section addressed one aspect of EVES with several scaled questions. That structuring is maintained throughout the remainder of this section.

[20] http://www.nast.at

5.4.1 Evaluating the Modelling Aspect of EVES

1- Are the Event Type Manager and the Category Manager together sufficient to model real-world situations regarding RSI?

(Yes - Completely, Yes - Largely, Yes - Sufficiently, Yes - Partly, Not Really)

The answers have shown that even though both managers are considered sufficient or largely sufficient, the answers highly depend on the usability of the managers, as the functions of the managers have to be understood clearly first in order to be able to judge about its sufficiency to model real world situations.

2- Are the Event Type Manager and the Category Manager intuitive to understand and use?

(Yes - Completely, Yes - Largely, Yes - Sufficiently, Yes - Partly, Not Really)

The answers have shown that the managers are considered only partly or sufficiently intuitive to understand and use. This result was expected, as one of the major objectives of EVES has been to provide utmost flexibility of the underlying data structures that resulted in a complex set of managers. At the current state a user has to be trained first to understand and use the managers efficiently.

3- How would you rate the necessity of the Module Manager?

(Absolutely Necessary, Very Important, Important, Practical, Not Necessary)

The answers have shown that the Module Manager was rated consistently as very important. This is understandable as it is a powerful tool that enables the user to compose different modules with different priorities and for different purposes to be used during the survey as desired.

4- Is the Module Manager intuitive to understand and use?

(Yes - Completely, Yes - Largely, Yes - Sufficiently, Yes - Partly, Not Really)

The answers have shown that the Module Manager is considered partly or sufficiently intuitive to understand and use. Again, this result was expected, because the amount of the provided flexibility results in various aspects that can be adjusted by the user, which in turn leads to confusion.

5.4.2 Evaluating the Preparations Aspect of EVES

1- Is the system sufficient to collect all data needed for an inspection?

(Yes - Completely, Yes - Largely, Yes - Sufficiently, Yes - Partly, No)

The results have shown that the system is considered to be largely sufficient to collect all data needed for an inspection. This aspect includes importing map information for the route to be inspected and importing previously defined points of interest to be alerted when approached during the survey.

2- Does the system facilitate the required preparations to conduct RSIs compared to traditional procedures?

(Yes - Completely, Yes - Largely, Yes - Sufficiently, Yes - Partly, Not Really)

The results have shown that the system is considered to largely facilitate the required preparations to conduct a RSI.

5.4.3 Evaluating the Inspection Aspect of EVES

1- Is the user interface for the survey intuitive to understand and use?

(Yes - Completely, Yes - Largely, Yes - Sufficiently, Yes - Partly, Not Really)

The results have shown that the graphical user interface for the survey is considered to be intuitive to a large extent. This is a direct result of the close cooperation with the future users of the system during the development phase. During this phase it was very important that the future users knew exactly what the problems with the old procedures were and what functionalities they wanted from the new system.

2- To what extent does the system facilitate the registering of safety hazards compared to traditional procedures?

(Yes - Immensely, Yes - Largely, Yes - Sufficiently, Yes - Partly, Not Really)

The results have shown that the system is considered to facilitate the registering of safety hazard to a large extent. The same as above can be said about this result. Because the system has been tested throughout the development phase during real RSIs, it was possible to identify limitations and desired functionalities early on and to integrate them in the end system.

5.4.4 Evaluating the Post-processing Aspect of EVES

1- How do you rate the usefulness of the events being presented on the map?

(Very Useful, Useful, Practical, Imperceptible, Not Useful)

The results have shown that it is considered practical that events can be seen on the map. Apparently the location of the registered events on the map of a scale that can be presented within the system is not considered very useful. We think that this opinion might change if the system is used more to conduct RSIs on the lower road network.

2- How do you rate the usefulness of the synchronisation of the video data with the registered events?

(Very Useful, Useful, Practical, Imperceptible, Not Useful)

The results have shown that the usefulness of the synchronisation of the video data with the registered events is considered very useful. This result was expected because using the system the user has no longer search back and forth in the videotape to find the position of a registered event, etc. Using EVES he can simply take a registered event and is presented with its position within the video, or he can move about within the video and is presented with the events that have been registered for that part of the inspection.

3- How do you rate the usefulness of the automatic localisation of the registered events in form of kilometre information?

(Very Useful, Useful, Practical, Imperceptible, Not Useful)

The results have shown that the usefulness of the automatic localisation of the registered events in form of kilometre information is considered very useful as it frees the user from determining the kilometre information by searching for the events within the videotape.

4- How do you rate the usefulness of being able to select pre-defined attributes of events?

(Very Useful, Useful, Practical, Imperceptible, Not Useful)

The results have shown that being able to select pre-defined attributes of events is considered practical. We think that this result is due to the fact that the system has not yet been used to conduct RSIs for different application fields. As the application fields will increase the need for more detailed inspection results will arise. At this point the function to assign pre-defined common attributes to events is going to prove useful in order to avoid redundant work.

5- Is the interface for post-processing intuitive to understand and use?

(Yes - Completely, Yes - Largely, Yes - Sufficiently, Yes - Partly, Not Really)

The results have shown that the interface for post-processing is considered intuitive to a large extent. Again we think that this is the result of the close cooperation with future users of the system during the development phase.

5.4.5 Evaluating the Reporting Aspect of EVES

1- How do you rate the usability of the Report Template Editor?

(Completely Sufficient, Largely Sufficient, Sufficient, Partly Sufficient, Not Sufficient)

The results have shown that the Report Template Editor is considered to be sufficient to a large extent. This is understandable if the current procedures to compose reports are examined. Currently, every report has to be generated manually even if their structure are the same. Using the Report Template Editor, however, the user can even define different structures that may be required by different authorities the reports are generated for. These templates are later used to generate the reports automatically.

2- How do you rate the coverage of the Report Template Editor?

(Completely Sufficient, Largely Sufficient, Sufficient, Partly Sufficient, Not Sufficient)

The results have shown that the coverage of the Report Template Editor is considered sufficient to a large extent. This is the result of having analysed current common templates for reports. Even if other report structures would be required in the future, the system could still be used to automatically generate the reports by using the template editor to generate a new template for the new structure.

3- How do you rate the usefulness of being able to generate reports automatically?

(Very Useful, Useful, Practical, Imperceptible, Not Useful)

The results have shown that the usefulness of being able to generate reports automatically is considered useful. The reasons for this are being mentioned above.

5.4.6 Evaluating the Monitoring Aspect of EVES

1- How do you rate the usefulness of being able to perform control surveys?

(Very Useful, Useful, Practical, Imperceptible, Not Useful)

The results have shown that the ability to perform control surveys is considered very useful. With traditional approaches the procedure to undertake a control survey would be almost as resource demanding as the RSI itself. With EVES, however, the procedures are highly facilitated as it enables the user, among other things, to select the events that he wants to control in advance and is then alerted by the system when the event is approached.

2- How do you rate the coverage of the monitoring system to perform all the steps required for a control inspection?

(Completely Sufficient, Largely Sufficient, Sufficient, Partly Sufficient, Not Sufficient)

The results have shown that the coverage of the monitoring system to perform the steps required to perform control inspections is considered sufficient to a large extent. Again the advantage of a close cooperation with the future users can be observed. However, we assume that further requirements might emerge as the system is used more and more to perform control inspections.

5.4.7 Evaluating the Analysis Aspect of EVES

1- How do you rate the coverage of the provided analysis functionalities?

(Completely Sufficient, Largely Sufficient, Sufficient, Partly Sufficient, Not Sufficient)

The results have shown that the coverage of the provided analysis functionalities is considered sufficient to a large extent. We already mentioned that the analysis functions in EVES are limited and could be extended in the future.

2- How do you rate the integrated section evaluation functionality?

(Very Useful, Useful, Practical, Imperceptible, Not Useful)

The results have shown that the integrated section evaluation functionality is considered to be useful. This functionality allows the user to automatically compute the safety class of sections. This is especially useful to determine sections considered for control surveys.

5.5 Conclusions

In the previous section the evaluation results of EVES were presented. Because EVES is a complex and multifaceted system a questionnaire with twenty questions was constructed that addressed different aspects of the system. An analysis of the results leads to the following lists of strengths and also limitations of the system that have to be addressed in the future.

The main limitations of EVES can be listed as follows:

- **Complexity**: As mentioned before, EVES is a complex system and contains several tools of which the complete functionality is difficult to grasp with current interfaces.
- **Limited Analysis Functionality**

These limitations lead to the following points for future work:

- **Usability**: To provide better understandability and usability, some of the current interfaces have to be re-designed in cooperation with the users.
- **Analysis**: Even though we consider the integration of sophisticated analysis methods within the framework, it could be necessary to develop additional specific analysis functions if required by the road inspectors.

Even though these points are substantial and have to be considered, we conclude with the strengths of EVES as confirmed by our evaluation results:

- **Flexibility**: EVES provides flexibility at several levels. It provides the definition and use of flexible data structures, modules, etc.
- **Facilitating control surveys**: EVES facilitates the conduction of control surveys by avoiding redundant work that has been already covered during the original inspection, etc.
- **Facilitating post-processing**: EVES facilitates post-processing to a large extent by avoiding redundant work procedures, enabling automatic report generation, etc.
- **Basic analysis functionality**: EVES provides basic analysis functionality as required for current inspections.

CHAPTER 6

6 A Case Study to demonstrate the Framework

The previous Chapter 5 has shown how data that is relevant for road safety research should be gathered. This chapter describes how such data can be used within the Road Traffic Safety Framework for research purposes. Because data with the aimed scope is not available yet, existing accident data from the US is used for demonstration. Chapter 6.1 will describe the data set, its scope and the reasons why this data set was chosen.

In Chapter 6.2 hypotheses are reviewed in order to demonstrate the possibilities of a comprehensive computer system with sufficient data and the possible mistakes in case of sparse data. Four selected hypotheses will cover different aspects of the work of a researcher where one own hypothesis shows how simple it is to get desired results.

Chapter 6.3 shows the capabilities of our framework regarding automated knowledge discovery. A basic statistical method is implemented on the data, simulating the working principle of a Data Warehouse. The results are presented and discussed. The chapter closes with a resume and an outlook of the possibilities in this area.

6.1 Information about the used Data Set

The goal of our framework is to build a computer aided system that allows gathering, storing and utilization a huge amount of road safety related data and information. A data set to be used to simulate this part of the framework had to have the following qualities.

- Sufficient amount of data for statistical analysis
- Sufficient complexity to simulate a data warehouse

The US Data set was found to be the one that fulfill these requirements at best. Further, its public availability was an additional reason for the selection, because it allows an easy revision of the results stated in this thesis.

6.1.1 Data Provider

The data is collected and provided by the National Highway Traffic Safety Administration (NHTSA)[21], belonging to the U.S. Department of Transportation. The data set is called General Estimates System (GES) and is part of the National Automotive Sampling System (NASS). GES is directed by the National Center for Statistics and Analysis, which is a component of Research and Development in NHTSA. The data set is publicly available and can be accessed over the internet[22].

The data collectors gather the data from approximately 400 police agencies within 60 geographic sites across the United States. Selected police traffic crash reports (PAR) are coded manually into the data set to provide a representative sample of the estimated 6 million police reported crashes per year [NHTSA, 2008, pp 4-6]. Information about the statistical quality and the estimated standard errors can be found in [NHTSA, 2008, pp 229-248].

6.1.2 Content of the Data set

The GES data set is a collection of several data sets that are grouped thematically. The data is coded into these data sets by trained personal directly from the PARs. Some information are redundantly stored in several data sets to enable analysts to work with only the data sets they need. Each record in the data sets has however a unique ID named 'casenum' so that all data sets can be merged together if needed. Detailed information about all the data sets can be found in [NHTSA, 2008, pp 19-126] while following the list of the data sets is given:

[21] www.nhtsa.com
[22] ftp://ftp.nhtsa.dot.gov/GES

- Accident Data Set
- Event Data Set
- Vehicle Data Set
- Distract Data Set
- Factor Data Set
- Maneuver Data Set
- Trafcon Data Set
- Violation Data Set
- Vision Data Set
- Person Data Set
- Impair Data Set
- Nmaction Data Set
- Safetyeq Data Set
- Biketraf Data Set

The main data set is the accident data set, while the other data sets include additional information. The vehicle and the person data sets are the ones with the most important information related to road safety research and are therefore selected for the demonstration of the framework. The datasets are distributed in the so called SAS7BDAT format, a specific format for statistical analyses. Because standard analysis software works as a black box and are not proper for the demonstration the datasets are converted into excel files with the software Stat/Transfer from Circle Systems. The three generated excel data sets were then merged into one MS Access database while duplicate information was neglected. The complete list of all parameters that are available in the collection of the selected three data sets can be found in [NHTSA, 2008, pp 13-18].

6.2 Revising hypothesis for traffic safety

As mentioned earlier, it is important to show the potential benefits of the proposed framework for researchers. For that purpose four well known hypothesis were chosen to be revised with the US data set. Further an own hypothesis is stated and checked to demonstrate the simplicity of research with the right tools at hand.

6.2.1 Influence of Alcohol on the severity of the injury

The influence of alcohol on road accident is a well studied area and therefore a very good point to begin our test/demonstration. At first, we will look at the effect of using alcohol or drugs on the severity of the accident. It is known that alcohol and drugs reduce the attention of the driver and therefore raise the risk of an accident. However there are only a few studies if this also raises the severity of the accident.

One of these studies is [Smink et al., 2008] in which the authors checked all drivers that was admitted to the trauma center in Tilburg in Netherlands, for the period from May 2000 to August 2001. All 106 Drivers were tested on alcohol in the blood and on drugs in the urine. The severity was expressed as the "injury severity score" according to [Baker et al., 1974]. The result of that study has been that there is no direct relation between the use of alcohol or drugs and the severity of the injury.

Another study by the same authors resulted in the same conclusion. In [Smink and Egberts, 2009] the blood samples of 993 drivers involved in a crash during the period from October 1998 to September 1999 were analyzed. The blood samples were screened for the presence of alcohol, illicit drugs and medicinal drugs and were linked to accident characteristics as available from the National Transport Research Centre in Netherland.

The accident reports in USA however indicate that alcohol has an influence on the severity. To analyze the interaction, four severity levels as 'no injury', 'slight injury', 'incapacitating injury' and 'fatality' were defined. The 459 accidents with unknown injury severity were excluded. Table 6-1 shows the spreading of this 4 severity levels over all accidents and accidents with or without alcohol involvement. Please note, that the data set has no information about drug use, therefore only alcohol was considered.

	No Injury	Slight Injury	Incapacitating Injury	Fatality
All Accidents	24729	22253	8898	1113
With Alcohol	1686	1881	1559	270
Without Alcohol	23043	20372	7339	843

Table 6-1: Injury severity related to alcohol involvement

First we look at the distribution of the injury severities over the alcohol involvement. As shown in Table 6-2, the last two severity levels have a higher percentage for accidents with alcohol involvement then the overall value. Consequently the accidents with no alcohol involvement have a higher percentage for the prior two severity levels.

	No Injury	Slight Injury	Incapacitating Injury	Fatality
All Accidents	% 43,39	% 39,04	% 15,61	% 1,96
With Alcohol	% 31,24	% 34,86	% 28,90	% 5,00
Without Alcohol	% 44,66	% 39,48	% 14,23	% 1,63

Table 6-2: Distribution of severity level over alcohol involvement

Afterwards we look at the distribution of the alcohol involvement over the severity levels. 103Table 6-3 shows clearly an increase of the injury severity level for accidents with alcohol involvement and the corresponding decrease for accidents without alcohol involvement.

	No Injury	Slight Injury	Incapacitating Injury	Fatality
With Alcohol	% 6,81	% 8,45	% 17,52	% 24,25
Without Alcohol	% 93,19	% 91,55	% 82,48	% 75,75

Table 6-3: Distribution of alcohol involvement over severity level

Figure 6-21 and Figure 6-2 visualize these results. Please note, that these are nominal scales. The lines between the values are to highlight the increase respectively the decrease between the injury severities.

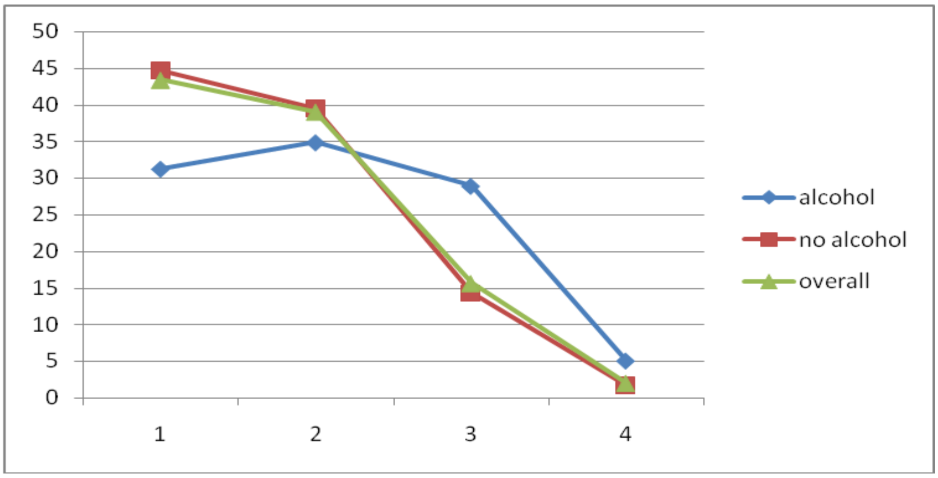


Figure 6-1: Distribution of severity level over alcohol involvement

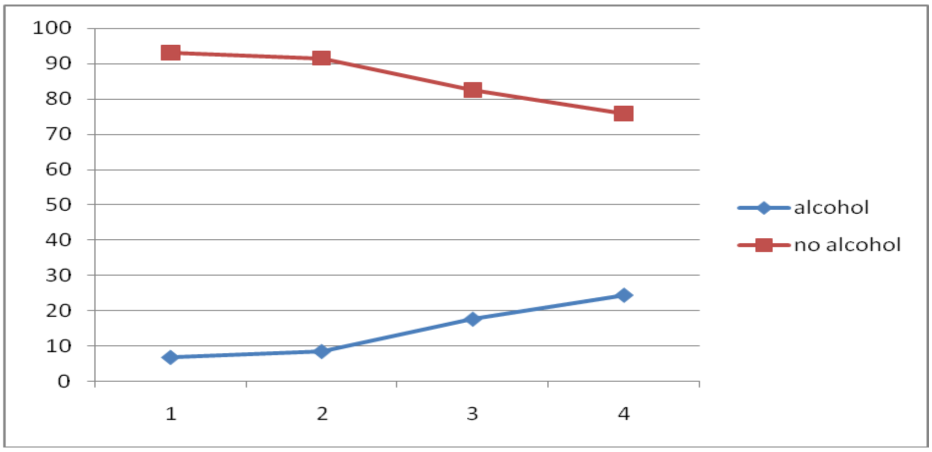


Figure 6-2: Distribution of alcohol involvement over severity level

Discussion

To understand the results and mismatch of the hypothesis, the differences between the referenced study from Netherlands and this study should be taken into account. The most important difference is that the referenced study only looks at the alcohol or drug usage of the driver and again only at the injury severity of the driver. In our study however also the alcohol involvement and injury of non-drivers are being taken into account. A drunken driver who causes an accident with a cyclist who is injured badly is a good example for a case, which would be not considered in the referenced study.

A further limitation of the first referenced study is the selection of drivers that were admitted to the trauma center. This means an a priory exclusion of those drivers with alcohol or drugs in their blood, who were not seriously injured and therefore not admitted to the trauma center. Also the injury severity of the driver, which is the most secured person in modern vehicles, is not implicitly a good indicator for the severity of the accident.

The absence of this limitations and the large count of accident data that is considered in our analysis allows the conclusion, that alcohol has a direct impact to the severity of the accident. There are also limitations in our data that can be investigated in some smaller detailed studies. The most important limitation is the missing information about drug usage. Another interesting question would be the level of alcohol consumption.

6.2.2 Influence of Speed on the accident risk and accident severity

Speeding is one of the biggest causes for accidents. Countermeasures like speed limits and psychological driver trainings are an attempt to decrease the number of speed related accidents. However the overestimation of one’s own skills in addition to the subjective safety feeling caused by safety equipment in modern cars seems to prevent the intended accident reduction. At this point one important question is what influence the speed has on the accident risk and affects the severity of the accident.

In [Elvik et al., 2006] the authors present a comprehensive study about speed and road accidents. 98 studies were used for a meta-analysis with the goal to apply the ‘power model’. The power model described in Gören Nilsson’s dissertation [Nilsson, 2004] suggests that the number of fatal accidents, serious injury accidents including fatal accidents and all accidents change in proportion to, respectively, the fourth, third and second power of the relative change in the mean speed of traffic.

Figure 6-3 shows for instance the power model for accidents with injury depending on the initial speed. The result of the study can be summarized as following: There is a statistical relationship between speed and road safety that holds for all speeds in the range between 25 km/h and 120 km/h. The exponents according to the power model were found as 4.5 for fatalities and 3.0 for serious injuries. [Elvik et al., 2006, pp 98ff]

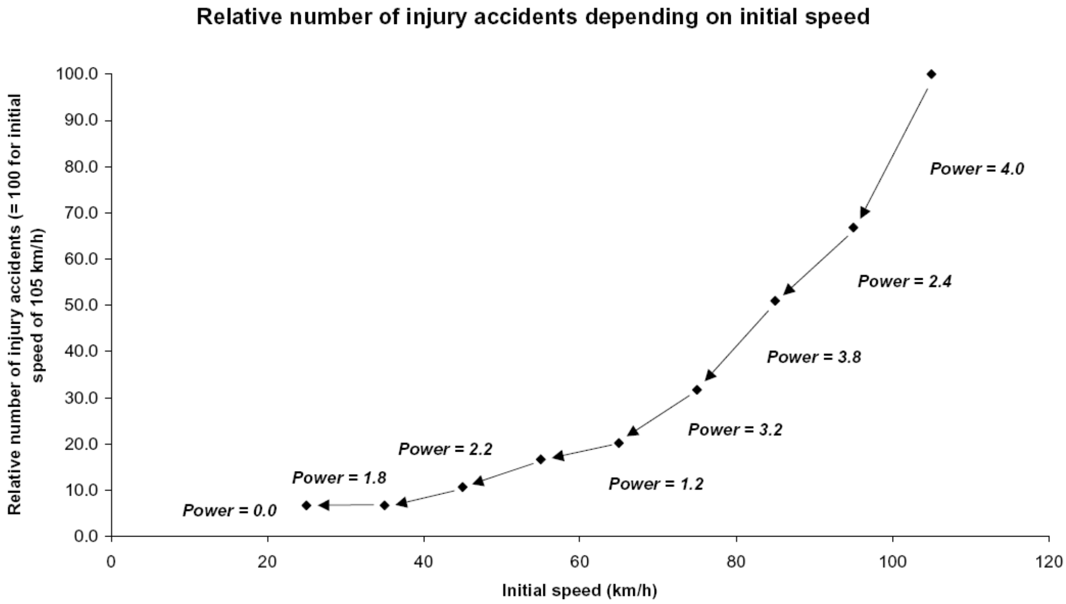


Figure 6-3: Relative number of injury accidents, depending on initial speed [**Elvik et al., 2006**, page 80]

A more detailed study is presented in [Kloeden et al., 1997]. In this study from Australia, the risk of involvement in a casualty crash depending on the travelling speed for sober drivers are evaluated for the metropolitan area of Adelaide within the 60 km/h speed limit zones. Also the relationship between travelling speed and the blood alcohol concentration (BAC) of the driver is explored.

The results are in the same line as the study above. 68% of the cars involved in a casualty crash were exceeding 60 km/h compared to 42% of those cars not involved in a crash. The difference increases with the travelling speed and is 14% compared to 1% at a travelling speed faster than 80 km/h.

Regarding the relationship between alcohol and speed, the study results indicate a slight increase of the travelling speed coming with higher alcohol concentration. An overview is given in Table 6-4. As one can see, low BAC rates have a two-fold effect, where some drivers reduce their travel speed where some drivers drive faster. For high BAC rates however no drivers reduce their speed and the highest percentage travels faster.

BAC Group	*Number of Cases*	*Average Speed(km/h)*	*% slow < 55 km/h*	*% normal 55 - 65 km/h*	*% fast > 65 km/h*
zero	833	60.04	12.7	73.9	13.3
.005	78	60.64	17.9	64.1	17.9
.010 - .045	71	61.14	14.1	97.6	18.3
050+	20	62.90	-	75.0	25.0
Total Positive	169	61.12	14.2	66.9	18.9

Table 6-4: Speed Distribution by Driver's BAC, [**Kloeden et al., 1997**, page 52]

Before analyzing these results some limitations of the US data should be pointed out in advance. First, there is only data about accidents, meaning there is no information about the overall traffic which makes it impossible to compare the likelihood of an accident with and without speeding. Further, not for all accidents are the travelling speed and the speed limit recorded. To be exact, from 100503 vehicles involved in the recorded accidents, for only 41293 the speed information is available. Despite these limitations it is possible to perform meaningful analysis which supports the stated relation between speed and accident risk.

Therefore the distribution of speed related accidents on the different over speeds should be investigated. From the 41293 vehicles mentioned above, 4153 (10.05%) was involved in a speed related accident. This percentage increases with the extent of the over speed somewhat linear fashion. Table 6-5 shows the exact distribution of vehicles involved in speed related accidents while only the 3478 vehicles that were driving above the speed limit are considered. Figure 6-4 visualizes the growing percentage of speed related accidents with increasing speed limit. Please note that the data is from the USA and therefore all speed information is in miles per hour (mph) rather than km/h like in the referenced studies from Europe.

Overspeed	*0 – 5 mph*	*5 – 10 mph*	*10 – 15 mph*	*15 – 20 mph*	*20+ mph*
All Accidents	1365	845	512	266	490
Speed related	279	349	303	191	400
% of speed related	20,04	41,30	59,17	71,80	81,63

Table 6-5: Distribution of accidents over the speed limits

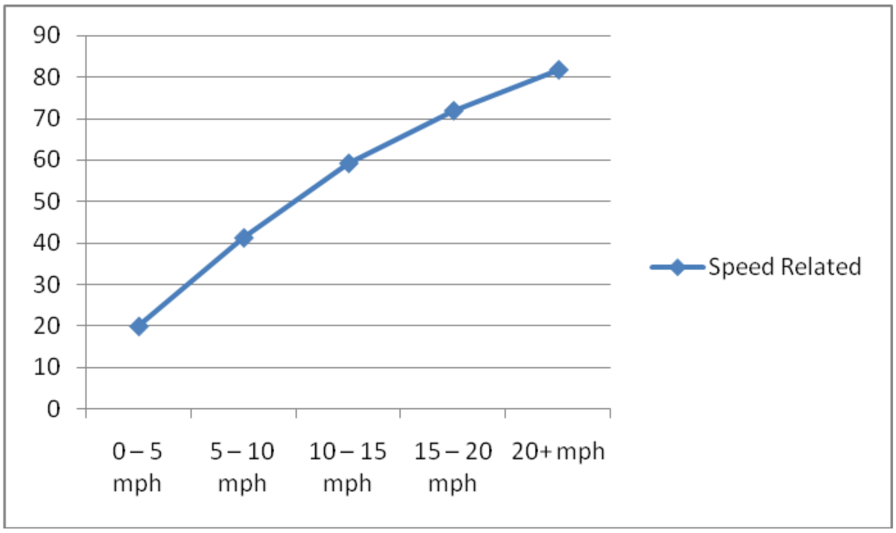


Figure 6-4: Percentage of speed related accidents with overspeed

Discussion

The results of the given studies from Europe and the results from the US data are both confirming that driving over the speed limit increases the accident risk immensely. Not only is a vehicle harder to control at higher speed, but also the probability to have a conflict with other vehicles that are driving within the speed limit, is higher. Increasing the speed limit may decrease the accident risk for those drivers with a low overspeed, but will increase the risk of that ones with high overspeed.

As already seen in the previous subchapter 6.2.2 alcohol has a direct effect on the injury severity. The fatality increases from 1,68% to 4,50% for alcohol related accidents. However, in combination with speeding, alcohol becomes more violent. The fatality increases for speed related accidents with alcohol involvement to 7.94%. The amount of severe injuries for this combination is with 33,77% also very high, compared to the 27,38% for alcohol related accidents or the overall value of 14,73%.

6.2.3 Effect of the Seating Position on the Safety of Children aged under 12

Road accidents are a major cause of death and serious injury to children. It is therefore important to analyze the safety risks for children in road accidents. This hypothesis points out that seating in the front seat increases the safety risk compared to seating in the rear of the vehicle.

In their study from Australia, [Lennon et al., 2008] analyzed accident data from the year 1993 to 2004. Before presenting the results, the authors pointed out the following differences between the US and Australia regarding road traffic: [Lennon et al., 2008, page 4-5]

1. The proportion of passenger side airbags are smaller in Australia
2. Australian airbags are build different and are designed to work as a supplement to restraints
3. Restraint use for children under 12 is with 90% higher than in the US with 82%

The study classifies injuries in only two groups, one for no or minor injuries, and one for severe injuries or fatalities. The results are similar to the study by Durbin and colleagues from the US [Durbin et al., 2005], giving an increase of the Relative Risk for serious injuries of 59% for children under the age of 4 seated in the front. For minor injuries the Relative Risk is still higher with 35% for the same age group. The Relative Risk decreases with increasing age, while the highest risk for children 0-1 years with a Relative Risk of 228%. All results are summarized in Table 6-6.

	RR	%95 CI	RR	%95 CI
	Serious Injury		*Minor Injury*	
Rear * Front	**1.00**		**1.00**	
0-3 years	1.59	1.10 – 2.28	1.35	1.17 – 1.60
4-7 years	1.10	0.90 – 1.34	1.12	1.05 – 1.20
8-12 years	0.93	0.82 – 1.05	1.07	1.03 – 1.12
<1 years	3.28	1.67 – 6.45	1.44	0-94 – 2.21
1-3 years	1.39	0.91 – 2.14	1.36	1.15 – 1.60

Table 6-6: Maximum likelihood estimates of relative risks
[**Lennon et al., 2008**, page 16]

The overall conclusion drawn from both studies above is that an appropriate restraint is the most important safety measure while the seating in the rear is an additional safety precaution. [Lennon et al., 2008, page 15] recommends mandating the rear seat for children under 12 years, particularly those aged 4 and younger.

	Aged 0-3		Aged 4-7		Aged 8-12	
	Front	*Rear*	*Front*	*Rear*	*Front*	*Rear*
No injury	166	2310	266	1653	1185	1363
Minor injury	37	483	85	484	287	412
Sever injury	6	70	25	68	53	71
Fatality	0	6	0	4	0	1
SUM	**209**	**2869**	**376**	**2208**	**1525**	**1847**

Table 6-7: Injury severity of children in different age groups for front and rear seat

Because being appropriate restrained is the major demand, for our study, only the 9129 restrained children out of 11795 are considered to focus on the affect of the seating position. The same three age groups with 3084, 2598 and 3447 children are used, where the injury is classified in the four groups of no injury, minor injury, sever injury and fatality. Table 6-7 gives an overview of our results.

The results indicates that the percentage of sitting in the front row rises with the age of the children, while there is no general rule for the injury severity. Because of the thankfully small number of fatalities, only the first three injury groups can be considered for the analysis, giving a small increase of risk for children aged 0-3, a clear increase for children aged 4-7 and a small decrease for children aged 8-12 years. Figure 6-5 shows the percentages of the injury severities for each age group sitting in the front row of the vehicle.

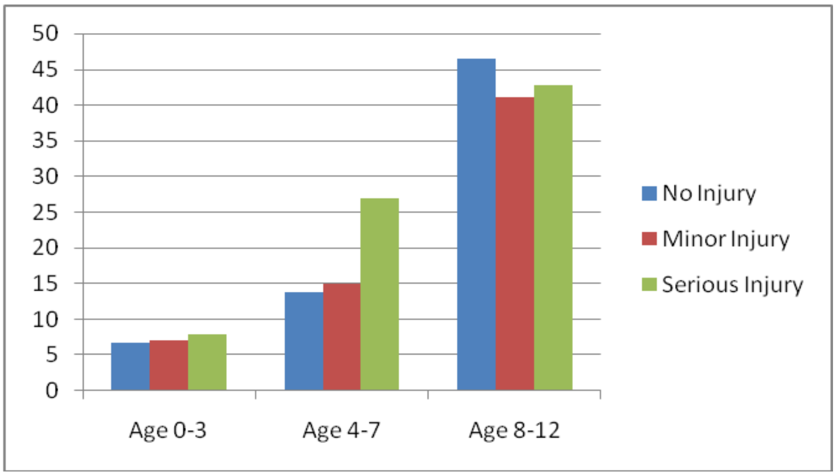


Figure 6-5: Percentage of Injury severity of children seating in the front row

Discussion

The most surprising result of this analysis is that the additional risk of sitting in the front row is significantly higher for children aged 4-7 than for younger children, which contradicts with the result of the other two cited studies, especially with the one from Australia. The reason for this contradiction could be the circumstance, that the cited studies used data that is 10-15 years old. Safety equipments inside the vehicle and restraint systems, especially those for little children are under continuous improving. The results of our study indicate that the safety systems for the youngest children are highly improved, but that there is still a lot of work to do to improve restraint systems for children aged 4-7 years.

Another important outcome of our study is the clear need of real time research using actual data that is not too old.

6.2.4 Affecting Influences of Rear-End Crashes

The study was conducted in Australia by Baldock and colleagues [Baldock et al., 2005] is in fact not a hypothesis, but a study to understand the nature of rear end crashes. They used police reported crash data from the years 1998 to 2002. Rear end crashes were compared with other crash types regarding several parameters that might have an effect on rear end crashes. The result of the study can be summarized as that most rear end crashes occur on straight level roads by clear weather condition. An interesting outcome was that drivers of striking vehicles were more likely young and male than drivers of struck vehicles. Also, injury severity was lower for rear end crashes than other crash types. The following tables from Table 6-8 to Table 6-14 and Figure 6-6 show the detailed results of their study.

	Rear End	Other	Rear End (%)	Other (%)
Cross Road	19761	25806	32,4	18,2
Divided Road	18489	22129	30,3	15,6
Cross Road	14829	28975	24,3	20,4
Undivided Road	4769	42398	7,8	29,8
Multiple	1301	1817	2,1	1,3
Other	1875	20991	3,1	14,8
Total	***61024***	***142116***	***100***	***100***

Table 6-8: Rear End Crashes by different Road Layouts [**Baldock et al., 2005**, p. 4]

	Rear End	Other	Rear End (%)	Other (%)
Clear	55720	129957	91,3	91,4
Rain	5304	12158	8,7	8,6
Total	***61024***	***142115***	***100***	***100***

Table 6-9: Rear End Crashes by Weather Condition [**Baldock et al., 2005**, 2005, p. 5]

	Rear End	Other	Rear End (%)	Other (%)
Daylight	52647	105632	86,3	74,3
Night	6889	32648	11,3	22,9
Dawn or Dusk	1488	3835	2,4	2,7
Total	***61024***	***142115***	***100***	***100***

Table 6-10: Rear End Crashes by Daytime [**Baldock et al., 2005**, 2005, p. 5]

	Rear End	Other	Rear End (%)	Other (%)
Property Damage	50317	115352	82,5	81,2
Treated by Doctor	7011	6378	11,5	4,5
Treated by Hospital	3228	13977	5,3	9,8
Admitted to Hospital	454	5714	0,7	4,0
Fatal	14	695	0,0	0,5
Total	***61024***	***142116***	***100***	***100***

Table 6-11: Rear End Crashes by Accident Severity [**Baldock et al., 2005**, 2005, p. 5]

	Rear End	Other	Rear End (%)	Other (%)
Level	56457	124561	92,5	87,6
Slope	3384	12608	5,6	8,9
Crest of Hill	686	2787	1,1	2,0
Buttom of Hill	429	1666	0,7	1,2
Unknown	68	494	0,1	0,3
Total	***61024***	***142116***	***100***	***100***

Table 6-12: Rear End Crashes by Vertical Alignment of the Road [**Baldock et al., 2005**, p. 6]

	Rear End	Other	Rear End (%)	Other (%)
Straight	58688	126872	96,2	89,3
Curve	2315	14892	3,8	10,5
Unkown	21	352	0,0	0,2
Total	***61024***	***142116***	***100***	***100***

Table 6-13: Rear End Crashes by Horizontal Alignment of the Road [**Baldock et al., 2005**, p. 6]

	Striking	Struck	Striking (%)	Struck (%)
Male	34501	30912	60,4	54,1
Female	20199	24650	35,3	43,1
Unkown	2452	1590	4,3	2,8
Total	***57152***	***57152***	***100***	***100***

Table 6-14: Rear End Crashes by Horizontal Alignment of the Road [**Baldock et al., 2005**, p. 6]

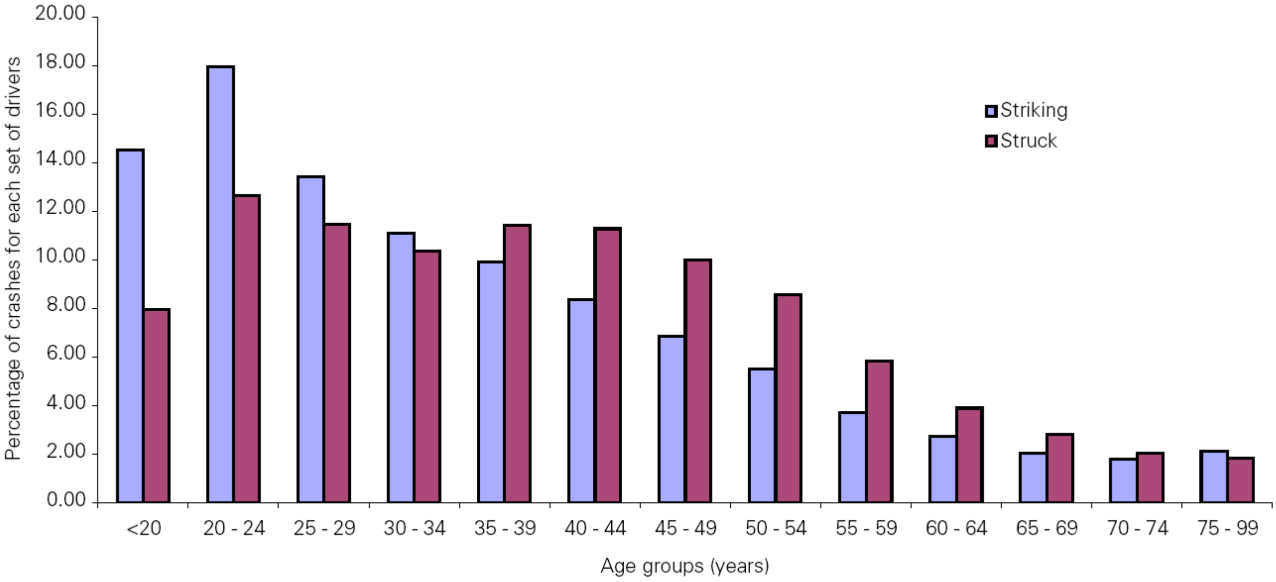


Figure 6-6: Rear End Crashes by Age for Striking and Struck vehicles

[**Baldock et al., 2005**, p. 6]

Discussion

Such in-depth studies are important to analyze several aspects of a specific road safety related issue and to gain a good overview. Performing in-depth studies becomes easier if there is enough data that is electronically accessible, which is a major target of our Framework. But it is also very important to read the outcomes properly and make correct deductions. Given the tables above it is for example correct to conclude that rear end crashes are less serious because they result in significantly less serious injuries.

However, the conclusion that rear end crashes occur more likely at daylight is not wrong, but also not true. The reason for the higher percentage at daylight is that single vehicle crashes included in “other” accidents happen more likely at night by low traffic density. It is also not wrong to say that most rear and crashes happen at clear weather, but this induces the idea that the weather has an effect on the likelihood of rear end crashes. Because other crashes have nearly the same percentage at clear weather, it is obvious that the weather has no effect on the crash type of the accident.

The results of our analysis with the US data gives similar results for most aspects, only age and gender seems to have a different role in rear-end crashes in the US. Men are represented with around 58% in both striking and struck vehicles. This is below the 60% of male drivers in all accident types. Also the age has no effect on the likelihood of being the driver of the striking vehicle, where all ages are represented with around 48%. Another remarkable difference is that young male drivers are with 54,92% significantly less represented in striking vehicles than old male drivers with 60,88%.

6.2.5 Affect of the Gender of the Front passenger on the Driver

The skill of the driver and the physical and psychological condition of the driver affects the way of driving and therefore the accident risk. Studies have shown that being aware of the police let people drive more carefully. But does the gender of a front passenger also has an either on the driver, either positive or negative? The following statements have to be proven for this hypothesis:

- A male passenger increases the likelihood of a drunk male driver.
- A female passenger increases the risk of a severe accident for a male driver.
- A male passenger increases the risk of a severe accident for a female driver.

The idea behind the statements is that a male driver could tend to drive risky in order to impress the passenger, while a male passenger could tell a female driver to engage risky driving. On the other side, female passenger could have a positive effect on the alcohol consumption of male drivers. To analyze these statements the 18521 drivers with passengers were analyzed. Table 6-15 shows the alcohol consumption of the driver, Table 6-16 shows the accident severity for the driver-passenger pairs.

	Male Passenger		**Female Passenger**	
	Alcohol	***No Alcohol***	***Alcohol***	***No Alcohol***
Male Driver	458	4810	246	5567
Female Driver	85	3172	91	4092
SUM	**543**	**7982**	**337**	**9659**

Table 6-15: Alcohol Consumption related to the gender of the passenger

	Male Passenger			
	No Injury	***Light Injury***	***Sever Injury***	***Fatality***
Male Driver	2999	1512	660	97
Female Driver	1654	1133	418	52
SUM	**4653**	**2645**	**1078**	**149**
	Female Passenger			
	No Injury	***Light Injury***	***Sever Injury***	***Fatality***
Male Driver	2932	2089	716	76
Female Driver	1968	1647	527	41
SUM	**4900**	**3736**	**1243**	**117**

Table 6-16: Injury Severity related to the gender of the passenger

Discussion

The hypothesis about the alcohol consumption is confirmed by the accident reports. While only 4,23% male drivers with a female passenger had an alcohol related accident, the amount of alcohol related accidents for male drivers with a male passenger increases to 8,53%. For female drivers the effect is much lower with 2,61% with male passengers compared with 2,17% with female passenger.

On the other hand, the hypotheses about the higher risk for severe accidents with a passenger from the opposite gender don't hold. The results indicate that a female passenger decreases the risk for male and female drivers, compared with the risk of those with a male passenger. The psychological effect of a female passenger on the driver should be investigated further to build a consciousness so that drivers drive always as they were a female passenger on their side.

6.3 Knowledge Discovery

The task of finding unknown dependencies out of present data is called Information Extraction. Data Warehouse (DWH) systems provide the user with various analysis tools to perform such tasks. But in order to use a DWH, the data has first to be integrated and adapted, which is usually done by a DWH-Expert. The user can later use the system, but he only gets the result from a black box, without knowing the internal steps. A standard DWH system was therefore not an option and a subset of the US data was selected and analyzed with a statistical method for our demonstration.

6.3.1 Selecting Parameters and Analysis Techniques

The main goal of this subchapter is to demonstrate the possibilities and advantages of a computer system compared to manual analyzing. Therefore the minimum request to the used data was a wide range with a complexity that is not feasible for being analyzed by hand. On the other hand, the example must stay simple enough to keep the results overviewable and understandable.

Therefore 16 dimensions, called parameter, were selected from the data to perform the analysis. To reduce the complexity the value ranges of the parameters were grouped to a maximum of four values for each parameter. Table 6-17 shows these parameters and their grouped values in alphabetical order.

Parameter	Values	Range
Accident Type	1	Single accidents
	2	Rear-End and Rear-Front accidents
	3	Side accidents
Age	1	16 – 24 years old
	2	25 – 44 years old
	3	44 years and older
Alcohol	1	Alcohol involved
	2	No alcohol involved
Align	1	Straight line
	2	Curve
Body Type	1	Automobiles
	2	SUV and Jeeps
	3	Heavy Trucks and Bus
	4	Motorcycle
Gender	1	Male Driver
	2	Female Driver
Injury Severity	1	No Injury
	2	Slight Injury
	3	Sever Injury
	4	Fatality
Light	1	Daylight
	2	Dark
	3	Dim
Model Year	1	2005 – 2008
	2	2000 – 2004
	3	1900 – 1999
Month	1	December – January – February
	2	March – April – May
	3	June – July – August
	4	September – October - November
Profile	1	Level
	2	Grade
	3	Hill
	4	Sag
Speed Limit	1	0 – 29 mph (~ 0 – 50 kmh)
	2	30 – 54 mph (~ 51 – 90 kmh)
	3	55 mph and over (~ 91 kmh and over)
Speed Related	1	Speed related accident
	2	Not speed related accident
Surface	1	Dry
	2	Wet or Icy
Weather	1	Clear
	2	Rain or Snow
	3	Fog or Smoke
Weekday	1	Monday – Friday
	2	Saturday - Sunday

Table 6-17: Selected parameters with value ranges from the US data set

A simple, but yet powerful method for Information Extraction is cross checking all possibilities. It means that, for example, the distribution of the three values for the parameter age over all accidents is compared with the age distribution for accidents filtered with the values of other parameters. If, for example, age has an effect on speeding, then the amount of young aged drivers for speed related accidents must be higher than for not speed related accidents.

For the selected, reduced dataset shown in table 6.x this would mean a total of 1.866.240.000 possible combinations. To reduce this number and increase the statistical quality of the results a threshold was defined, so that if any combination of several parameter values result in less than 500 accidents, this combination is rejected, because with that few data results would be not meaningful. There are for instance only 109 motorcycle accidents with a female driver. Therefore the distribution of the age of the driver is not computed for these accidents. This filter reduced the combinations to be computed to about 125.000.

6.3.2 Technical implementation of the analysis

The three original datasets from the NHTSA named accident, person and vehicle were transferred into a Microsoft Access Database. In order to perform the crosschecking, the selected parameters were taken from these 3 datasets and combined into one database table named “x_check”. From the person dataset only the drivers were selected. Data with missing information about one of the selected parameters were neglected. This resulted in a total of 81988 drivers in 50308 accidents.

To perform the crosschecking, this data had to be filtered with various parameter values. This is done by using the standard query language for databases, namely SQL. A sample SQL-Query would look like:

```
SELECT COUNT(*) FROM x_check
WHERE Alcohol = 1 AND Gender = 1
```

The “count” in the first line, simple returns the count of all data rows in the database table “x_check” that fulfill the given filter in the second row. The first line stays constant. This query would give the result 4798, which is the count of male drivers that have an accident with alcohol involvement. In the next step, the query would be changed to

```
“WHERE Alcohol = 1 AND Gender = 2”
```

giving the number 1784, which is the number of female drivers with an alcohol involved accident. Having these number, the distribution of the gender for all 6582 alcohol involved accident drivers can be computed as 72,90% male and 27,10% female.

A simple tool in Java has been developed to perform these SQL-Queries automatically and store the results for each parameter in CSV-Files. CSV stands here for "comma separated valued" and describes a plain text file, where a table is stored while each column is separated by commas. For each parameter a CSV-File was generated, where the first column contains the second line of the SQL-Query, giving the used filter. The following columns contain the resulted count and the percentage of each value of the parameter. The CSV-File for gender would look like the following, but containing about over 8000 rows.

```
                              ; 49516 ; 60,39 ; 32472 ; 39,61
Alcohol = 1                   ; 4798  ; 72,90 ; 1784  ; 27,10
Alcohol = 1 AND InjSev = 1    ; 1512  ; 73,51 ; 545   ; 26,49
Alcohol = 1 AND InjSev = 2    ; 1677  ; 71,03 ; 684   ; 28,97
Alcohol = 1 AND InjSev = 3    ; 1333  ; 73,97 ; 469   ; 26,03
```

The first row contains the distribution of the gender over all accidents without any filter. This is the comparing value, to detect dependencies between the parameters. In the given example above, one can see that male drivers are more represented in alcohol involved accidents compared with all accidents. This allows the deduction that male drivers tend more to drive drunk than female drivers. For the injury severity of the alcohol involved accident however, the gender of the drivers seems to have no effect.

In order to perform this analysis for all 16 parameters the generated CSV-Files were manipulated with Microsoft Excel, where the difference of each filtered percentage to the overall percentage were computed and the results were sorted by the maximum difference, to get the parameters that has the biggest effect on this parameter. The results of this analysis are given in the next subchapter.

6.3.3 Discussion of the Analysis Results

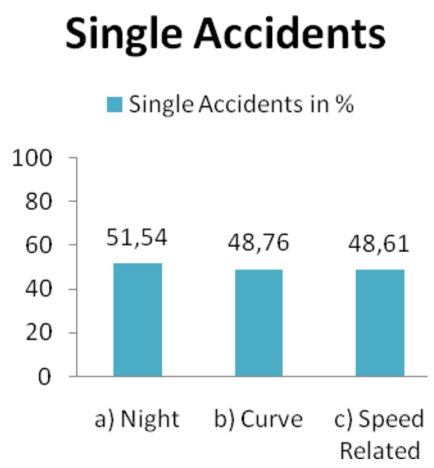
In this subchapter, some results of the Information Extraction done by the computer are listed and discussed in order to gain knowledge. For each parameter, the value with the maximum variance is selected. In the left column of the table are the affecting parameter values shown graphically. The right column contains the written form of the outcome, followed by a short discussion about their meaning. The results for model year, surface, weather and weekday are not listed, since they didn't give any interesting results.

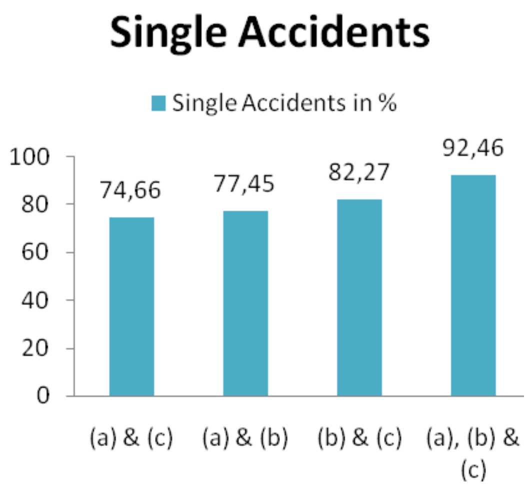
Results for the Parameter: Accident Type

Accident Type

Single Accidents

Overall Percentage: 20,34%





Details

- 51,54% of all accidents at night are single accidents.
- 48,76% of all accidents in curves are single accidents.
- 48,61% of all speed related accidents are single accidents.

- 74,66% of all speed related accidents at night are single accidents.
- 77,45 % of all accidents at night in curves are singe accidents.
- 82,27% of all speed related accidents in curves are single accidents.
- 92,46 of all speed related accidents at night in curves are single accidents.

Discussion

Single accidents happen when the driver loses control over the vehicle without any interference with other vehicles. The risk of losing control is naturally higher at higher speeds and in curves.

The less traffic volume at night decreases the probability of a conflict with other vehicles and therefore increases the amount of single accidents.

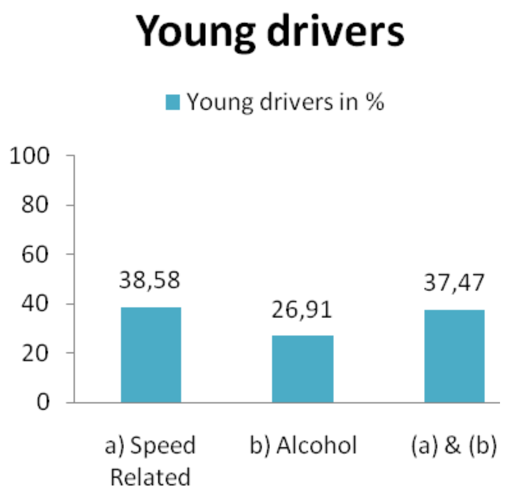
The most interesting outcome is that the combination of these three factors consequently increases the amount of single accidents. Better night-visibility in curves and speed reducing measures like dangerous looking curves should decrease the single accident risk.

Table 6-18: Parameters that affect the accident type

Results for the Parameter: Age

<table>
<tr><th colspan="2">Age
16 years to 24 years old</th></tr>
<tr>
<td>

Overall Percentage: 25,17%



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<td>

Details

- 38,58 % of all speed related accidents are young drivers.
- 26,91% of all accidents with alcohol involvement are young drivers.

- 37,47 % of all speed related accidents with alcohol involvement are young drivers.

Discussion

Young drivers tend more to over speed, which causes combined with the lack of driver experience a higher accidents risk.

On the other hand, one would expect, based on many research, that young drivers also will tend to drive drunk, but the analysis resulted that there is only a small increase of drunk drivers in this age group, while the combination of over speed and alcohol even decreases the accident risk compared with only speed related accidents.

The circumstance that in the US drinking at all is allowed after the age of 21 seems to have a positive effect on the drunk driving behavior of young aged drivers.

</td>
</tr>
</table>

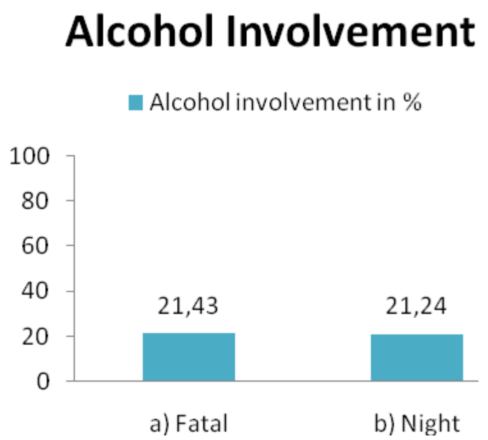
Table 6-19: Parameters that affect the age of the driver

Results for the Parameter: Alcohol

Alcohol

Alcohol involved

Overall Percentage: 8,03%



Details

- 21,43% of all fatal accidents are with alcohol involvement.
- 21,24% of all accidents at night are with alcohol involvement.

Discussion

There were no surprises at the results of alcohol related accidents. Alcohol is affecting the severity of an accident and is therefore more present at fatal accidents.

Since drinking is a social event that is undertaken most at evening or at night, the alcohol involvement is also higher at night accidents.

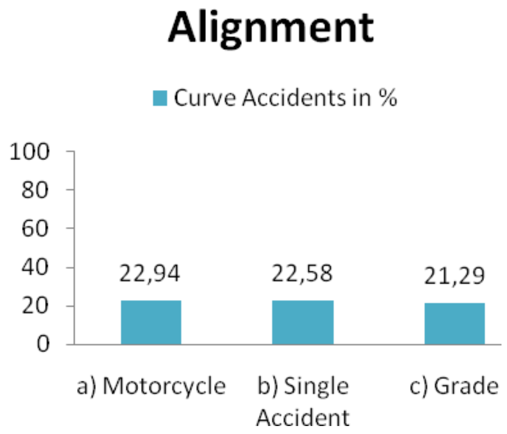
Table 6-20: Parameters that affect the alcohol involvement

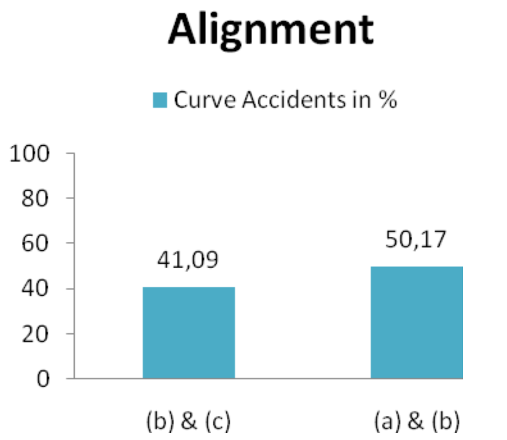
Results for the Parameter: Alignment

Alignment

Accidents in Curves

Overall Percentage: 9,42%





Details

- 22,94% of all accidents with motorcycles happen in curves.
- 22,58% of all single accidents happen in curves.
- 21,29% of all accidents on grade roads happen in curves.

- 41,09% of all single accidents on grade roads happen in curves.
- 50,17% of all single motorcycle accidents happen in curves.

Discussion

Motorcycles are duo to their physical form harder to control in curves than other vehicles with 4 tires. Therefore it is no surprise that they have more accidents in curves than other vehicles and that most of them are single accidents.

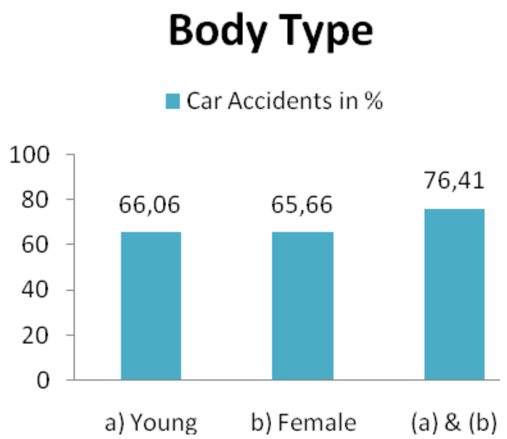
Surprising is the outcome, that the grade of the road in combination with single accidents happen more in curves. Level curves without a grade should therefore be safer.

Table 6-21: Parameters that affect the alignment

Results for the Parameter: Body type

<table>
<tr><th colspan="2">**Body Type**
Cars</th></tr>
<tr><td>

Overall Percentage: 52,64%



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Details

- 66,06% of all accidents of young drivers are with cars.
- 65,66% of all accidents with female drivers are with cars.
- 76,41% of all accidents with young female drivers are with cars.

Discussion

Without the knowledge about the distribution of the different body types among the drivers, no conclusion can be made out of these results.

But one can assume, that older male drivers are more likely to drive another vehicle type like motorcycles or heavy trucks which would explain the higher percentage of cars for young and female drivers.

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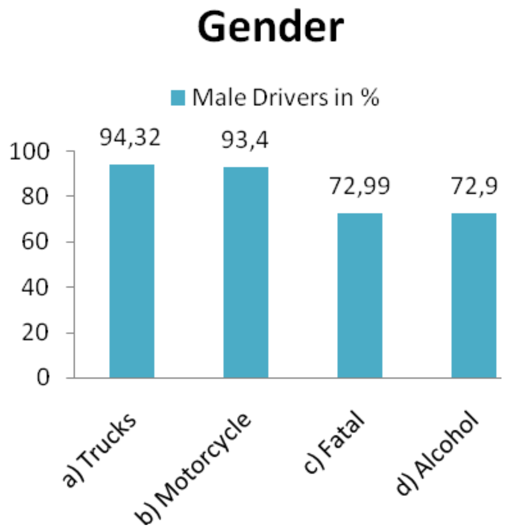
Table 6-22: Parameters that affect the body type

Results for the Parameter: Gender

Gender

Males

Overall Percentage: 60,39%



Details

- 94,32% of all trucks with accidents were driven by males.
- 93,40% of all motorcycles with an accident were driven by males.
- 72,99% of all fatal accidents had at least on male driver.
- 72,90% of all accidents with alcohol involvement had at least on male driver.

Discussion

The fact that most of the drivers of trucks and motorcycles in accidents are male, can be assumed to reflect the circumstance, that there are more male truck and motorcycle drivers than females.

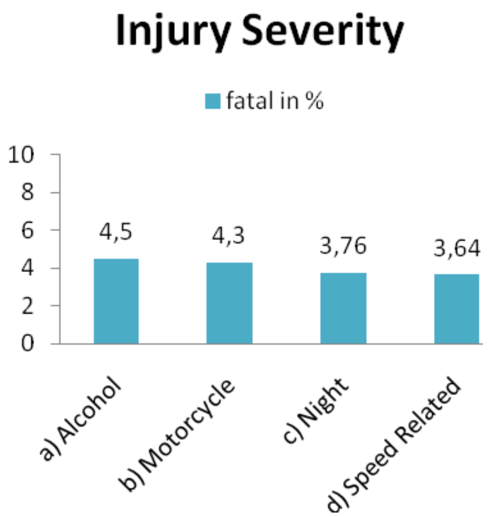
The high presence at fatal accidents is partly caused by the high present at motorcycle crashes, which are due to their nature more severe than accidents with vehicles. Another cause is the higher rate of drunk driving. Campaigns like “don’t drink and drive” should therefore address mainly male drivers.

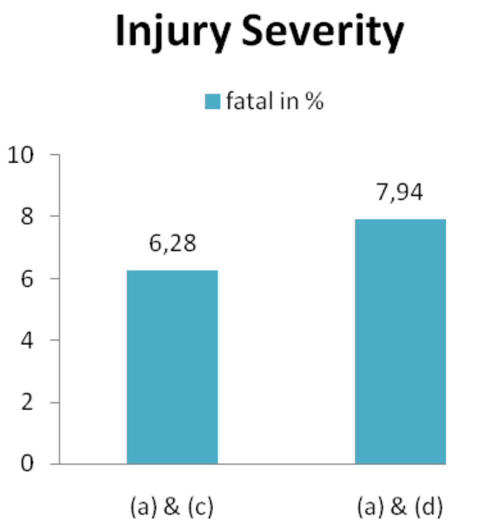
Table 6-23: Parameters that affect the alignment

Results for the Parameter: Injury Severity

<table>
<tr><th colspan="2">Injury Severity
Fatal</th></tr>
<tr><td>

Overall Percentage: 1,68%





</td><td>

Details

- 4,50% of all alcohol involved accidents are fatal.
- 4,30% of all motorcycle accidents are fatal.
- 3,76% of all night time accidents are fatal.
- 3,64% of all speed related accidents are fatal.

- 3,66% of all alcohol involved motorcycle accidents are fatal.
- 6,28% of all alcohol involved night time accidents are fatal.
- 7,94% of all speed related accidents with alcohol involvement are fatal.

Discussion

Alcohol and speed are well known the highest risk for road traffic accidents. This is especially true if they both are combined, with the maximum fatality rate of 7,94% for speed related accidents with alcohol involvement. Both speed related and alcohol involved accidents happen more at night, which explain the higher percentage for night time accidents.

Motorcycles have due to their physical form a higher risk. Only 3,15% of motorcycle accidents ends with no injury, while 33,47% have a severe injury and 4,30% end fatal.

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Table 6-24: Parameters that affect the injury severity

Results for the Parameter: Light Condition

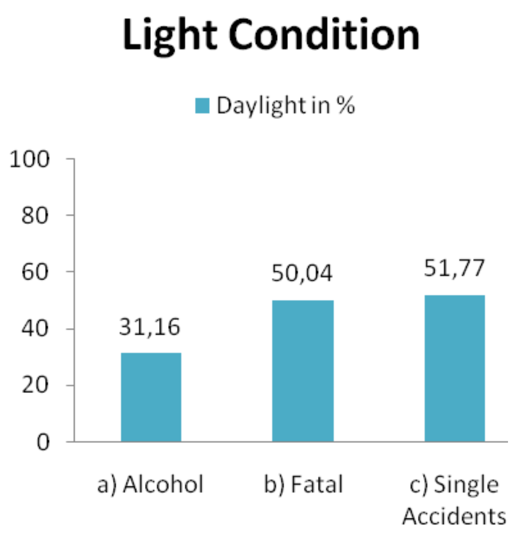
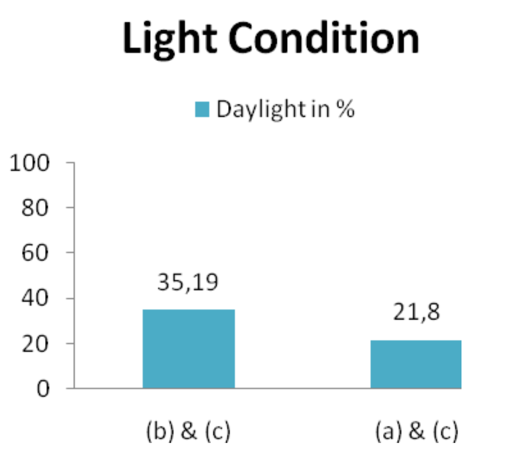
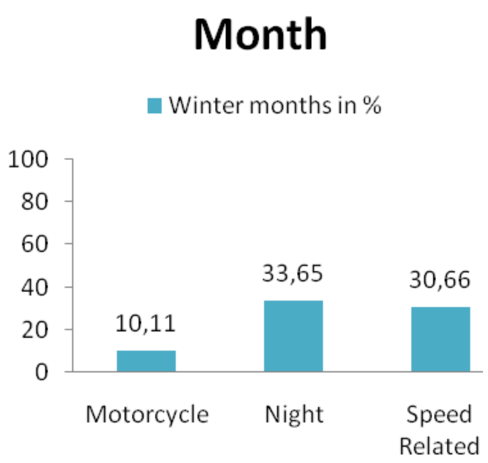
Light Condition Daylight	
Overall Percentage: 71,05%  	***Details*** • 31,16% of all accidents with alcohol involvement happen at daylight. • 50,04% of all fatal accidents happen at daylight. • 51,77% of all single accidents happen at daylight. • 35,19% of all fatal single accidents happen at daylight. • 21,80% of all single accidents with alcohol involvement happen at daylight. ***Discussion*** As a difference to the previous results, the values for this parameters goes down and could therefore be read backwards. So not 31,16% of all accidents with alcohol involvement happen at daylight, but 68,84% of them happen at the evening or at night. The most extreme value is for single accidents with alcohol involvement, where nearly 80% of them happen in dark hours.

Table 6-25: Parameters that affect the light condition

Results for the Parameter: Month

<table>
<tr><th colspan="2">Month
December – January - February</th></tr>
<tr>
<td>

Overall Percentage: 25,00%



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<td>

Details

- 10,11% of all motorcycle accidents happen in the winter months.
- 33,65% of all night time accidents happen in the winter months.
- 30,66% of all speed related accidents happen in the winter months.

Discussion

As a consequence of the weather, the usage of motorcycle is fewer in this winter months compared with the rest of the year. The increase of the night time accidents can be explained by the fact that the night is in this month's longer.

Only the increase of speed related accidents is interesting, indicating a relation between the bad weather and surface conditions and the control of the vehicle at higher speeds.

The age and gender of the driver and the weekday of the accident had no effect on the month of the accident.

</td>
</tr>
</table>

Table 6-26: Parameters that affect the month

Results for the Parameter: Profile

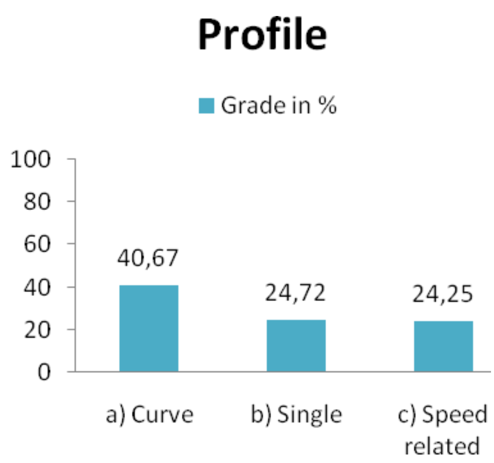
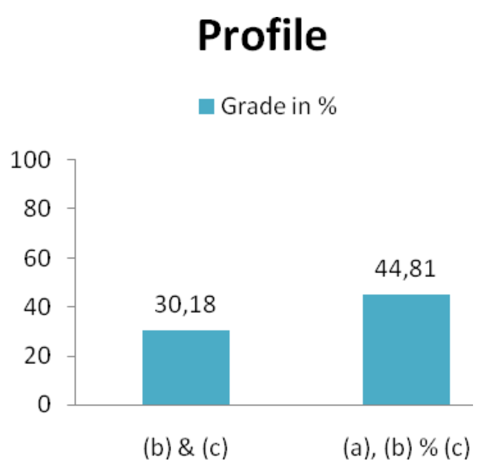
Profile Grade	
Overall Percentage: 17,99%   	***Details*** • 40,67% of all accidents in curves happen at graded roads. • 24,72% of all single accidents happen at graded roads. • 24,25% of all speed related accidents happen at graded roads. • 30,18% of all speed related accidents happen on graded roads. • 44,81% of all speed related single accidents in curves happen on graded roads. ***Discussion*** The high value for accidents in curves can be explained by the physical nature of curves which are often built graded. But the results indicate clearly that a graded road has a negative effect on the control of the vehicle which increases the amount of single and speed related accidents. The further increase while combining the parameters confirms this conclusion. As an implication, building flat roads with no grade would have a positive effect on the road traffic safety.

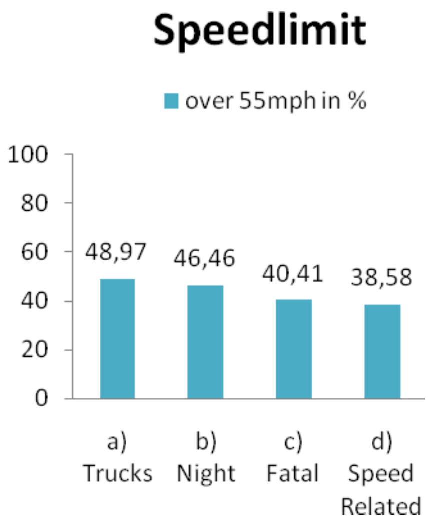
Table 6-27: Parameters that affect the profile

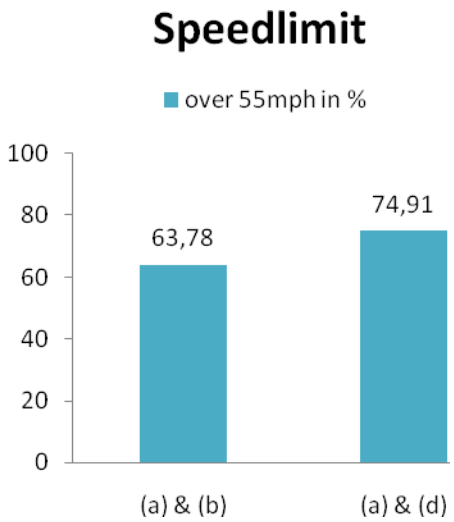
Results for the Parameter: Speedlimit

Speedlimit

Over 55mph

Overall Percentage: 25,87%





Details

- 48,97% of all accidents with trucks happen on roads with a speed limit over 55mph.
- 46,46% of all night time accidents happen on roads with a speed limit over 55mph.
- 40,41% of all fatal accidents happen on roads with a speed limit over 55mph.
- 38,58% of all speed related accidents happen on roads with a speed limit over 55mph.

- 74,91% of all speed related accidents with trucks happen on roads with a speed limit over 55mph.
- 63,78% of all night time accidents with trucks happen on roads with a speed limit over 55mph.

Discussion

A speed limit of 55mph or higher, which is equivalent to 90kmh, indicates freeways or highways, which would explain the higher percentage of truck and nighttime accidents, and the combination of these two. Also the higher amount of speed related and fatal accidents are no surprise.

However the speed related accidents of trucks has to be addressed in order to decrease the count of accidents.

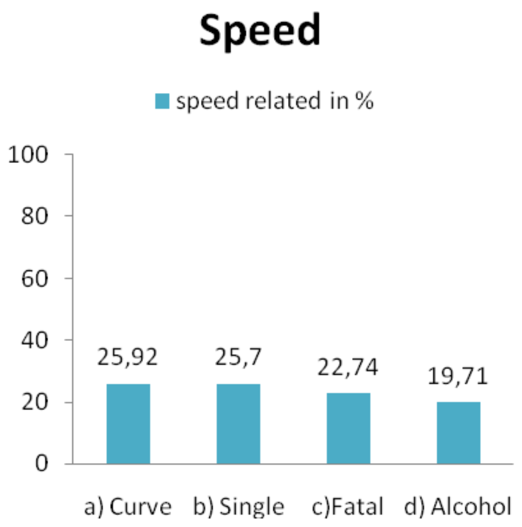
Table 6-28: Parameters that affect the speedlimit

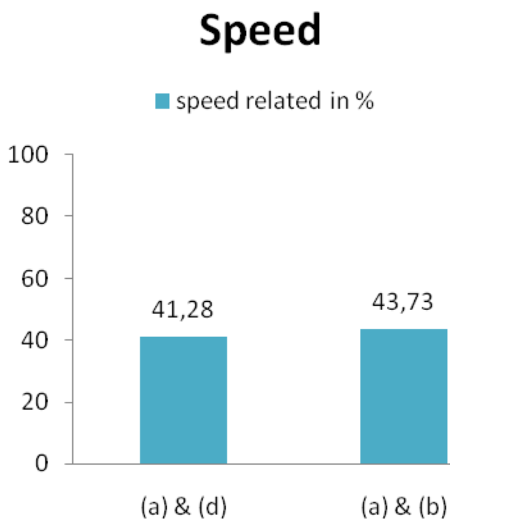
Results for the Parameter: Speed

Speed

Speed related

Overall Percentage: 10,53%





Details

- 25,92% of all accidents in curves are speed related.
- 25,70% of all single accidents are speed related.
- 22,74% of all speed related accidents are speed related.
- 19,71% of all accidents with alcohol involvement are speed related.

- 41,28% of all alcohol involved accidents in curves are speed related.
- 43,73% of all single accidents in curves are speed related.

Discussion

The connection between alcohol and speed and between speed and the injury severity are known. But speed seems also to have a very important influence on accidents in curves.

Speed regulating measures in curves are recommended to make them safer and to decrease the amount of curve accidents. Additional traffic signs or dangerous looking designs could be effective and should be further investigated.

Table 6-29: Parameters that affect the speed

CHAPTER 7

7 Outlook and Recommendations

If the life of thousands of humans lost in traffic accidents every year is more worth than the profit of a big market chain, then the research in the area of road traffic safety should be at least on the same technological level as the market analyzing systems of such industries. The research in the field of road traffic safety in this thesis, performed by a computer scientist, does not have revealed many new findings about safety risks or possible treatments. But it has clearly shown the need and the possibilities of a comprehensive computer-based system.

With the introduction of our Road Traffic Safety Framework, this thesis is meant to be a starting point to encourage computer scientists and road traffic planners to work together and build the needed infrastructure to perform state of the art research with sufficient data. During the course of this thesis, the framework is defined and one important part of it, namely the tool for performing Road Safety Inspections (RSIs) to gather information about the road and its environment, is developed.

The author of this thesis will continue his work in this field with the goal to fully develop the framework in collaboration with other researchers and students. The work that needs to be done can be summarized as follows:

- Developing the Traffic Conflict Reporting Portal
- Developing a tool to include accident reports
- Defining a dynamic data warehouse structure
- Developing tools to enable researchers use the data warehouse

The authorities have to be willing to implement and use the tools in order to achieve the desired goals. This is at one point, a question of the costs compared to the expected benefits. The costs of implementing RSIs on the higher road network in Austria, consisting of 2.000 km motorways and 18.000 km highways is already calculated as about 750.000€ per year. This is expected to be the most expensive part of the framework.

The other parts of the framework, especially the several data sources and the data warehouse are planned to be built into different authorities. Here the bureaucratic structure has to be taken into account. To avoid problems, an overall authority should regulate the implementation and the data exchange.

Depending on the extent of the data exchange between the authorities, data privacy could also become an issue. For instance, it could be beneficial to track a persons activities over the years to find specific accident patterns. This of course has to be done anonymously, which can be achieved by a trustworthy authority that can assign to each real person a random ID-number to be used within the system. Every time a new record is being loaded into the data warehouse, this authority would return the ID-number of the person if he already is in the database, or give a new random ID if the person is new to the system. This way the researchers could assign different records to one person, without knowing any personal information about him.

Road traffic safety should be worth 0.10 – 0.20 € per citizen of a country. Therefore, we recommend strongly the full development and implementation of the introduced Road Traffic Safety Framework. Austria could be a good pilot project to test and demonstrate the benefits of the framework before adapting it in Europe and other countries.

CHAPTER 8

8 Summary

The road traffic is a complex system consisting of the human, the vehicle and the road, which all affect the traffic safety in different ways. The research and applications in this area to enhance traffic safety are widely spread. In this work, we concentrated on safety aspects related to the design and infrastructure of roads and their surroundings. The work in this area appears to have a great improvement potential by using computer technologies.

A comprehensive study of the actual state-of-the-art has shown that computers are partially used in different ways. The widest use is for statistical analyses of accident data. New projects like EuroRAP make a more comprehensive use of computer technologies, but are themselves limited in their coverage and objectives.

Studying the processes and methods related to the road traffic safety from the point of view of a computer scientist, they were considered in a data driven approach as consisting of the three parts of data gathering, data storing and data utilization. A framework that covers the whole of this lifecycle and of data that is relevant for road traffic safety, is introduced.

In the first part of the thesis, data that is relevant for road traffic safety is gathered. Here, we distinguished between data about accidents, data about the road and its surroundings, and data about conflict situations. Collecting accident data has a long history and is partially computer aided. However, the extent of both, the coverage of accidents and the coverage of the properties of the accidents is limited. Here, we bring up some ideas to improve that coverage.

The road safety inspections, which aim to gather data about the road itself is a relatively new method. This method is very cost demanding in the actual best practice and is therefore only performed on parts of the road network, even though it is intended to be performed periodically on the whole road network. However, data gathered using this method is essential to improve the road safety and hence, essential for the framework. For this purpose, a computer system was proposed to ease and facilitate the inspection, which together with the suggested implementation plan can reduce the overall costs for a complete RSI dramatically.

The last type of data is about conflict situations, which are in general never reported or captured. The normal method where an expert observes a spot, a junction, or a very short section for several days is only applied at points with a very high accident rate, because it takes several man/days work and provides only a little amount of data about a single spot. An improvement of the efficiency of this procedure using computer-based video technology seems at the present not possible, because they are not applicable for automated conflict detection. In this thesis, a new approach is introduced in form of an online reporting system, where the participants or eyewitnesses can report a conflict situation.

The implementation of this first part of the framework will produce a huge amount of data that has to be stored in an efficient way. To achieve this goal a three-tier architecture is suggested for the storage of the data. The lowest tier covers the systems that collect the data and use XML files in order to take the dynamic nature of the data into account and allow an efficiently communication between the different systems. The second tier consists of several databases that store the data from the XML files from the first tier. These databases are located within the bureaucratic hierarchy of the authorities, wherever needed. The last tier consists of a data warehouse, where all the gathered data is collected and aggregated.

The use of data warehouses is a common in many sectors, where there is such a huge amount of data, both in the commercial and the scientific field. In the field of road traffic safety, data warehouses are sometimes used for accident data analyses, but not in the extent proposed in our framework due to the limitations of the quantity and quality of existing data.

This three-tier storage architecture also favors the utilization of data, because it enables the scientist to utilize the data in new different ways. First of all, the process of checking the validity of a hypothesis becomes much easier, because the data warehouse provides all the data at one point and along with suitable methods for their analysis.

Furthermore, the data warehouse changes the shape of research by finding facts in the data by applying statistical methods to recognize patterns. So the scientist has no more to hypothesise, but to search for explanations of the found facts. These two ways of utilizing data will lead to new knowledge in the field of road safety in a shorter time, which will further improve the framework on the one hand, and the safety of the roads on the other hand.

One of the proposed systems of the framework has been developed within the course of this thesis, namely the computer-aided road safety inspection system that improves the feasibility of the framework and shows the possible benefits of applying common computer techniques to the field of Road Traffic Safety.

During the development it was seen that gathered data is written down in electronic text documents. This means that the information was available only in a human readable electronic form and not in a machine readable and usable form, which is essential for computer-based systems. Therefore, the first thing to do was to find out at which point of the current RSI procedure it would be best to put the data into the computer system. The easiest way would be to not change the actual process and only enter the gathered data into the system afterwards. But in order to save manpower and costs, the best point was identified as the earliest point possible, namely where the data was first gathered.

The developed software system has been designed to cover the complete inspection process, beginning with the preparations for the inspection. At this point there was not much potential for time saving. The next step is the on-site inspection survey. Here, the time saving was minimal as well, because the inspector has to drive through the section under any circumstances. The system can decrease the number of drives through the same section, but this is just a fraction of the general time needed. However, by gathering the data with the computer-aided system in connection with automatic GPS localization, the quality and usability of the data increases enormously.

The biggest time saving potential is in the post-processing stage. Because the data is already in a machine readably form, many tasks like creating human readable reports or generating overview maps are largely automated.

Developing a data warehouse from the scratch was out of the scope of this work and also not considered because of the missing data needed to fill a data warehouse. However, to test and demonstrate the possibilities of the introduced framework, some features of data warehouses were simulated using extensive road accident data from the United States.

For the first demonstration, four well known hypotheses about road safety related issues were selected and the existing literature was revised using the US data set. This demonstration revealed on the one hand, that analyses with few data can lead to misinterpretations. For instance, the study about child restraint systems where the referenced study used old data, clearly showed how important it is to use new up-to-date data. On the other hand, the simplicity of performing research on data if appropriate tools are present, was demonstrated by stating a new hypothesis about the effect of the gender of the front seat passenger and by revising it.

The second demonstration aimed to show the possibilities of information extraction and knowledge discovery, which is one of the most important features of data warehouses. For this purpose, 16 parameters were selected from the US data set and were analyzed by the computer-system using the cross checking method. The comprehensive results were presented and discussed, revealing some unknown dependencies between different parameters of the road traffic elements.

The field tests and demonstrations have clearly shown that the proposed road traffic safety framework is a realistic, feasible, and promising approach and should be developed and implemented in its full scope.

Bibliography

[Amundsen and Hydén, 1977] Amundsen F.H, Hyden C. ***Proceedings of the First Workshop on Traffic Conflicts***. Oslo: Institute of Transport Economics, 1977.

[AusRAP, 2008] **Comparing Risk Maps and Star Ratings**. AusRAP Technical Working Paper. http://www.ausrap.org, 2008

[Baker et al., 1974] Baker S.P, O'Neill B, Haddon W.Jr., Long W.B. ***The Injury Severity Score: A Method for Describing Patients with Multiple Injuries and Evaluation Emergency Care***. In *J. Trauma, Vol 14*, pp 187-196, 1974.

[Baldock et al., 2005] Baldock M.R.J, Long A.D, Lindsay V.L, McLean A.K. ***Rear End Crashes***. *CASR Report Series, CASR018*, Centre for Automotve Safety Research, September 2005.

[BASt and Sétra, 2005] **Networf Safety Management**. *National Guideline*. Federal Highway Research Institute, Bundesanstalt für Straßenwesen (BASt): Germany and Roads and Motorways Engineering Dept. (Sétra): France, 2005.

[Bensberg, 2001] Bensberg F. ***Web Log Mining als Instrument der Marketingforschung - Ein Systemgestaltender Ansatz für Internetbasierte Märkte***. Gabler Verlag: Wiesbaden, Germany, 2001.

[Cardoso et al., 2007] Cardoso J.L, Stefan C, Elvik R, Sørensen M. **Road Safety Inspection – Best Practice Guidelines and Implementation Steps**. RIPCORD-ISEREST, *Deliverable D5*, September 2007.

[Carnaby, 2004] Carnaby B. **Road Marking – High Priority Road Safety, or Just Road Maintenance?** In *Proceedings of the Road Safety Research, Policing and Education Conference*, 2004.

[Chin and Quek, 1997] Chin H.C, Quek S.T. **Measurement of Traffic Conflicts**. In *Safety Science*, 26(3): pp 169-185, 1997.

[Corben et al., 2005] Corben B, Koppel S, Oxley J, Johnston I. **Cost-effective Measures to Improve Crash and Injury Risk at Rural Intersections**. In *Proceedings of the Road Safety Research, Policing and Education Conference*, 2005.

[Crandall et al., 2002] Crandall J.R, Bhalla K.S, Madeley N.J. **Designing Road Vehicles for Pedestrian Protection**. *British Medical Journal (BMJ)*, 324 (7346): pp 1145-1148, 2002.

[Dao et al., 2005] Dao N.X, Anh T.T, Anh T.T, **Conflict Technique Applied to Traffic Safety on the Model Corridor of Ha Noi**. In *Proceedings of the Eastern Asi Society for Transportation Studies*, Vol. 5, pp 1875-1890, 2005.

[Delaney et al., 2003] Delaney A, Langford J, Corben B.F, Newstead S.V, Jacques N, Daly P. **Roadside Environment Safety**. In *Proceedings of the Road Safety Research, Policing and Education Conference*, 2003.

[Durbin et al., 2005] Durbin D.R, Chen C.I, Smith R, Ellitt M.T, Winston M.T. **Effects of Seating Position and Appropriate Restraint Use on the Risk of Injury to Children in Motor Vehicle Crashes**. *PEDIATRICS Vol. 115*, pp 305-309, March, 2005.

[Elvik, 2006] Elvik R. **Road Safety Inspections: Safety Effects and Best Practice Guidelines**. *TOI Report 850/2006*, Institute of Transport Economics (TOI): Norway, 2006

[Elvik et al., 2006] Elvik R, Christensen P, Amundsen A. **Speed and road accidents: An Evaluation of the Power Model**. *TOI Report 740/2004*, Institute of Transport Economics (TOI): Norway, 2004.

[Elvik, 2007] Elvik R. **State-of-the-art Approaches to Road Accident Black Spot Management and Safety Analysis of Road Networks**. *Work Package 6: Report 1,* RiPCORD-iSEREST, 2007.

[Erke and Gstalter, 1985] Erke H, Gstalter H. **Verkehrskonflikttechnik: Handbuch für die Durchführung und Auswertung von Erhebungen**. BASt Bergisch Gladbach, Unfall- und Sicherheitsforschung Strassenverkehr, Issue 52, 1985.

[Frawley et al., 1992] Frawley W.J, Piatetsky-Shapiro G, Matheus C J. **Knowledge Discovery in Databases: An Overview**. In *AI Magazine*, 13(3): pp 57-70, 1992.

[Glauz and Migletz, 1984] Glauz W.D, Migletz D.J. **Aplication of Traffic Conflict Analysis at Intersections**. NCHRP-Report 219, Transportation Research Board: Washington D.C, 1984.

[Hand et al., 2001] Hand D, Mannila H, Smyth P. ***Principles of Data Mining***. MIT Press: Cambridge, MA, 2001.

[Handbook222, 2006] **Road Safety Audits and Inspections**. Level 1 Handbook of the Norwegian Public Roads Administration’s Handbook Series: Norway. October, 2006

[Harano and Hubert, 1974] Harano R.M, Hubert D.E. **An Evaluation of California's 'Good Driver' Incentive Program**. *Report No 6*. Sacramento: California Division of Highways, 1974.

[HLEM, 2006] **Infrasture Safety in Europe: Evaluation of the Results of the Questionnaire**. High Level Expert Meeting on Infrastructure Safety, Vienna 2006.

[Hobbs, 1987] Hobbs F.D. ***Traffic Planning and Engineering: Institution of Highways and Transportation, Accident Reduction and Prevention****, Second Edition*. United Kingdom: Pergamon Press, 1987.

[Hoyos et al., 1995] Hoyos C.G, Fastenmeier W, Gstalter H. **Forderungen An Eine Verhaltensorientierte Verkehrssicherheitsarbeit**. In *Autofahrer und Verkehrssituation (Fastenmeier Ed.)*: pp 11-26. Verlag TÜV Rheinland-Deutscher Psychologen Verlag: Cologne-Bonn, 1995.

[Hydén, 1977] Hydén C. **A Traffic Conflicts Technique for Examining Urban Intersection Problems**. In *Proceedings of the First Workshop on Traffic Conflicts*, pp. 87-98. Oslo: Institute of Transport Economics, 1977.

[Hydén, 1987] Hydén Ch. **The Development of a Method for Traffic Safety Evaluation: The Swedish Traffic Conflict Technique**. *Bulletin 70*, University of Lund, Lund Institute of Technology, Department of Traffic Planning and Engineering, 1987.

[iRAP, 2008] **Vaccines for Roads**. Report, International Road Assessment Programme (iRAP), July 2008.

[Kloeden et al., 1997] Kloeden C.N, McLean A.J, Moore V.M, Ponte G. **Travelling Speed and the Risk of Crash Involvement**. University of Adelaide, NHMRC Road Accident Research Unit, 1997.

[Lamm and Kloeckner, 1984] Lamm R, Kloeckner J.H. **Increase of Traffic Safety by Surveillance of Speed Limits with Automatic Radar Devices on a Dangerous Section of a German Autobahn: A Long-term Investigation**. In *Transportation Research Record*, 974: pp 8-16. Washington, D.C: Transportation Research Board, 1984.

[Larsson et al., 2003] Larsson M, Candappa N, Corben B. **World's Best Practice in the Use of Flexible Barrier Systems Along High-Speed Roads**. In *Proceedings of the Road Safety Research, Policing and Education Conference*, 2003.

[Leeming, 1969] Leeming J.J. ***Road Accidents: Prevent or Punish?*** Quinta Press: England, 1969.

[Lennon et al., 2008] Lennon A.J, Siskind V, Haworth N.L. **Rear Seat Safer: Seating Position, Restraint Use and Injuries in Children in Traffic Crashes in Victoria, Austria**. *Accident Analysis and Prevention*, pp: 829-834, 2008.

[Lonero and Clinton, 1998] Lonero L.P, Clinton K. Changing Road User Behavior: What Works, What Doesn't. PDE Publications, 1998.

[Lutschounig et al., 2005] Lutschounig S, Nadler H, Mocsári T. **Description of the Current Practice of RSI**. RIPCORD ISEREST, Report: RI-KUSS-WP5_R1_V5, September 2005.

[Lynam et al., 2004] Lynam D, Hummel T, Barker J, Lawson S.D. **European Road Assessment Programme EuroRAP I (2003) Technical Report**. EuroRAP, 2004.

[Lynam et al., 2007] Lynam D, Castle J, Scoons J, Lawson S.D, Hill J, Charman S. **European Road Assement Core Programme II (2005-6) Technical Report**. EuroRAP II, 2007.

[Macaulay et al., 2002] Macaulay J, Tziotis M, Fildes B. **Evaluation of Perceptual Countermeasure Treatments**. In *Proceedings of the Road Safety Research, Policing and Education Conference*, 2002.

[Martinez, 2000] Martinez R. **How to Reach the Optimal Traffic Safety Environment: The American Perspective**. In *Transportation, Traffic Safety and Health*, pp 29-47. Springer-Verlag: Berlin Heidelberg New York, 2000.

[Matena et al., 2008] Matena S, Louwerse W, Schermers G, Vaneerdewegh P, Pokorny P, Gaitanidou L, Elvik R, Cardoso J. **Best Practice on Road Design and Road Environment**. RIPCORD-ISEREST, *Deliverable D3*, February 2008.

[Moscari and Hollo, 2006] Moscari T, Hollo P. **Common Understanding on Road Safety Inspections**. RIPCORD ISEREST: Report of Workpackage 5, 2006.

[Muhlrad, 1993] Muhlrad N. **Traffic Conflict Techniques and Other Forms of Behavioural Analysis: Application to Safety Diagnoses**. In *Proceedings of the 6th ICTCT Workshop*, 1993.

[Muhlrad and Dupré, 1984] Muhlrad N, Dupré G. **The French Conflict Technique**. In *International Calibration Study of Traffic Conflict Techniques*. Springer Verlag: Berlin Heidelberg, Germany, 1984.

[Nadler and Lutshounig, 2006] Nadler H, Lutschounig S. **Analysis of the Common Understanding Approach**. RIPCORD ISEREST Report: RIPCORD-ISEREST_KfV_WP5_V2, 2006.

[Nast, 2006] **Überprüfung der Marktsituation**. Nast Consulting, Internal Report, 2006.

[NHTSA, 2008] **National Automotive Sampling System General Estimates System – Analytical User's Manual 1988-2007**. National Highway Traffic Safety Administration, 2008

[Nilsson, 2004] Nilsson G. **Traffic Safety dimensions and the Power Model to describe the effect of speed on safety**. *Lund Institute of Technology, Department of Technology and Society, Bulletin 221*, Lund 2004.

[Nilsson and Prior, 2004] Nilsson K, Prior N. ***Wire Rope Safety Barriers and the Pacific Highway Program: RTA Research and Investigations***. In *Proceedings of the Road Safety Research, Policing and Education Conference*, 2004.

[Ogden, 1996] Ogden K.D. ***Safer Roads: A Guide to Road Safety Engineering***. Aldershot: Ashgate Publishing/Avebury Technical, 1996.

[Perkins and Harris, 1967] Perkins S.R, Harris J.L. **Traffic Conflict Characteristics: Accident Potential at Intersections**. General Motors Research Laboratory, Report 718, 1967.

[Retting and Greene, 1997] Retting R.A, Greene M.A. **Influence of Traffic Signal Timing on Red-Light Running and Potential Vehicle Conflicts at Urban Intersections**. In *Transportation Research Record*, No: 1595. National Academy Press: Washington DC, 1997.

[Risser and Schützenhöfer, 1984] Risser R, Schützenhöfer A. **Application of Traffic-Conflict Technique in Autria**. In *International Calibration Study of Traffic Conflict Techniques*, pp. 141-151. Springer Verlag: Berlin Heidelberg, Germany, 1984.

[Risser et al., 1991] Risser R, Zuzan W.D, Tamme W, Steinbauer J, Kaba A. **Handbuch zur Erhebung von Verkehrskonflikten mit Anleitungen zur Beobachterschulung**. Wien: Literas Universitätsverlag, 1991.

[Rothengatter, 1992] Rothengatter T. **The Effects of Police Surveillance and Law Enforcement on Driver Behavior**. *Current Psychology*, 2(3): pp 349-358, 1992.

[Rumar, 1985] Rumar K. **The Role of Perceptual and Cognitive Filters in Observed Behavior**. In *Human Behavior and Traffic Safety* (L. Evans and R.C. Schwing, eds.). New York: Plenum Press, 1985.

[Sayed, 1997] Sayed T. **Estimating the Safety of Unsignalized Intersections Using Traffic Conflicts**. Third International Symposium on Intersections Without Traffic Signals, pp 230-235, 1997.

[Shinar and McKnight, 1985] Shinar D, McKnight A.J. **The Effects of Enforcement and Public Information on Compliance**. In *Human Behavior and Traffic Safety* (L. Evans and R.C. Schwing, eds.), pp. 385-419. New York: Plenum Press, 1985.

[Smink et al., 2008] Smink B.E, Movig K.L, ijkhuizen A, Lusthof K.J, de Gier J.J, Egberts A.C, Uges D.R. **The relationship between the use of psychoactive substances and the severity of the injury of a group of crash-involved drivers admitted to a regional trauma center**. In *Traffic Injury Prevention,* pp. 105-108, September 2008.

[Smink and Egberts, 2009] Smink B.E, Egberts A.C. **The relationship between drug use and traffic accident severity**. In *Drugs, Driving and Traffic Safety*, pp. 135-150, Birkhäuser Basel Verlag, 2009.

[Smith, Daly and McInerney, 2007] Smith G, Daly P, McInerney R. **AusRAP Star Ratings for the Australian National Network**. In *Proceedings of the Road Safety Research, Policing and Education Conference*, 2007.

[Sørensen, 2007] Sørensen M. **Best Practice Guidelines on Black Spot Management and Safety Analysis of Road Networks**. *TOI Report 898/2007*, Institute of Transport Economics (TOI): Norway, November 2007.

[Sørensen and Elvik, 2005] Sørensen M, Elvik R. **Black Spot Management and Safety Analysis of Road Networks – Best Practice Guidelines and Implementation Steps**. RIPCORD ISEREST: Report of Workpackage 6, 2005.

[Supreme, 2007] **Best Practices in Road Safety: Handbook for Measures at the European Level**. Summary and Publication of Best Practices in Road Safety in the Member States, June 2007.

[VisionZero, 2006] **Safe Traffic – Vision Zero on the Move**. Swedish Road Administration, 2006.

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