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Real World Data on Driver Behaviour in Accidents and Incidents

Evaluating data collection and analysis methods
for car safety development

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Gothenburg, Sweden, 2012

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Abstract

Real world data is important for safety development within the road transportation system. For car safety development in particular, methods to collect and analyse real world data on driver behaviour from normal driving, incidents and accidents are needed to address safety in driving.

This thesis investigates what different analysis methods applied to self-report and observation data can provide about driver safety issues (e.g., drowsiness, distraction) in accidents and incidents. Nonresponse analysis and adjustment in an accident mail survey was performed by using insurance data from 8519 survey recipients and mail survey data for the respondents in Paper I. Document case studies were performed for 158 accidents in Paper II by combining accident mail survey questionnaires and insurance documents. In Paper III, an incident causation analysis was performed based on video-recordings of 90 car-to-pedestrian incidents in a naturalistic driving study.

The findings imply that self-reported and observation data collection procedures are both required as complementary sources of information for car safety development. Mail surveys can be used as a cost efficient method to collect general information from a large number of accidents as well as information on some driver safety issues. Valuable, additional information about accidents can be obtained by analysing written descriptions from mail survey and insurance documents. This can provide insights into how the driver experienced the accident, facilitate the interpretation of mail survey responses, and provide information that is not captured by the mail survey variables. Video-recordings from naturalistic driving studies can provide detailed information on many driver safety issues. This is especially valuable for aspects of driver behaviour that is difficult to capture with self-report methods.

There is ample opportunity to improve the understanding of driver safety issues in accidents and incidents. By combining data from self-reported and recorded events, future studies can improve estimates of the occurrence of different driver safety issues and provide a wider picture of accident and incident causation. A combination of different types of data sources can also be used to further address the validity of accident mail surveys.

Keywords: Mail survey questionnaire, Naturalistic driving study, Statistical analysis, Case study, Incident causation, Contributing factors, Driver safety issues, Driver behaviour, Car safety development

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List of papers

Paper I Tivesten, E., Jonsson, S., Jakobsson, L., Norin, H. (2012). Nonresponse analysis and adjustment in a mail survey on car accidents. Accident Analysis & Prevention (In Press). doi:10.1016/j.aap.2012.02.017

Contribution: The study was designed, analysed and authored by Tivesten. Jonsson, together with colleagues at Volvia, extracted the data.

Paper II Tivesten, E., Wiberg, H. (submitted). What can insurance and police reports provide in addition to mail survey variables alone when analyzing driver safety issues in accident situations?

Contribution: The study was designed, analysed and authored by Tivesten.

Paper III Habibovic, A., Tivesten, E., Uchida, N., Bärgman, J., Ljung Aust, M. (submitted). Driver behavior in car-to-pedestrian incidents: An application of the Driver Reliability and Error Analysis Method (DREAM).

Contribution: All authors participated in the modification of DREAM and the compilation of the causation charts. Habibovic and Tivesten reviewed the charts and aggregated these, and outlined the study. Tivesten discussed the implications of using the DREAM method on naturalistic driving data and participated in the writing process of the other parts of the paper.

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Abbreviations

ADAS	Advanced Driver Assistance Systems
DREAM	Driver Reliability and Error Analysis Method
EDR	Event Data Recorder
FOT	Field Operational Test
NDS	Naturalistic Driving Study

Glossary

Self-report methods	Methods of data collection by asking the persons involved. Includes e.g., questionnaires, interviews, focus groups, and driving diaries.
Observation methods	Methods of data collection where the situation and persons involved are observed. In road safety research this can be on-site or in-vehicle observation, and performed by a person or recorded on video.
Naturalistic Driving Studies (NDS)	Unobtrusive observation of driving in a natural setting for a long period of time (e.g., one year). Vehicles are equipped with sensors, video cameras and data loggers that register information about the vehicle, the driver and the traffic environment.
Field Operational Test (FOT)	FOT use the same data collection procedures as NDS, but are designed to evaluate the effect of different functions in real traffic. These functions could for instance be forward collision warning (FCW), lane departure warning (LDW) etc.
Contributing factors	Circumstances that contributed to the occurrence of an accident or incident.
Driver safety issue	A contributing factor explained from the driver's perspective.
Causation	How several contributing factors are linked and together explain why an accident or incident occurred.
Mail survey	A pen and paper questionnaire sent out by regular mail.
Insurance documents	Includes insurance claim reports by the involved road users, and in some cases written letters from involved road users or witnesses, and police reports.
Auxiliary data	Variables available for all mail survey recipients, obtained from another source than the mail survey.

1. Introduction

1.1. Background

About 1.3 million people die every year, and up to 50 million are seriously injured in road traffic accidents across the world (WHO 2009). These numbers are predicted to increase, unless immediate effective actions are taken. The UN has described the current situation as a safety crisis, and in 2010 they proclaimed a "Global Plan for the Decade of Action for Road Safety 2011-2020", encouraging safety development efforts within the whole road transportation system for all countries and regions around the world (UN 2010). On a national level, the most well known effort is the Vision Zero. The Vision Zero was formulated by the Swedish National Road Administration and accepted by the Swedish Parliament in 1997 (Johansson 2009). Several other countries and organisations have followed this example by adopting similar visions (Peden et al. 2004, Elvebakk and Steiro 2009, Corben et al. 2010, Eugensson et al. 2011). The Vision Zero states that: “No one shall be killed or seriously injured within the road traffic system.” This statement makes a clear standpoint; any loss of life or severe personal injury is unacceptable. A prerequisite for such a development is that it should not limit the individual needs for mobility, freedom nor the growth of society. This is a challenging task that requires efforts within infrastructure, vehicle design, and driver education. Furthermore, a wider safety perspective than injury prevention in collisions are required, addressing safety in driving as well as in collisions. Real world data can provide knowledge about current safety issues that can be addressed by developing safety countermeasures within the road transportation system.

1.2. The need for real world data in car safety development

For vehicle manufacturers, real world data is an important part of car safety development. Volvo Cars, e.g., uses a working process where real world data is an integral part of the product development (Isaksson-Hellman and Norin 2005). From the early years until the end of the 1990s, car safety was mainly focused on injury prevention in collisions, which has substantially reduced the number of injuries (Isaksson-Hellman and Norin 2005). In more recent years, the safety scope has been extended to cover both injury prevention in collisions as well as accident prevention (Eugensson et al. 2011).

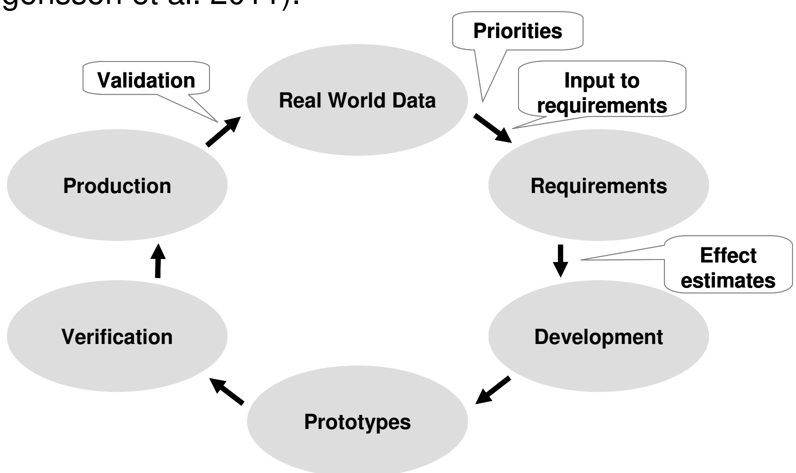

Figure 1: An overview of how real world data are used within the working process of car safety development.

Figure 1 illustrates the working process, described by Almqvist et al (1982), and how real world data is used in several ways within this process. First, real world data is used to identify the most common/severe safety issues. From this information a safety **priority** is formulated and used for strategic decisions. Second, detailed descriptions of the prioritized real world situations and knowledge about the mechanisms behind injuries and accidents are needed. This knowledge can support the formulation of the **requirements** on a customer level that are independent of technical solutions. The requirements are formulated to resemble real world situations in a physical or virtual test environment, and are continuously used during the development process. When choosing among competing conceptual solutions, real world data can be used to make **effect estimates** of the safety impact, see for instance Korner (1989) and Lindman and Tivesten (2006). When new car models are introduced on the market, their safety performance can be **validated** in real life. Examples of real life validation are studies on the efficiency of electronic stability control (ESC) (Erke 2008), anti-lock brake systems (ABS) (Evans 1999), side impact protection system (SIPS) (Jakobsson et al. 2010) and whiplash protections system (WHIPS) (Jakobsson and Norin 2004).

Detailed data is needed to understand the mechanism behind accidents and injuries and representative data is needed to understand how frequently different types of safety issues occur (Norin 2010). Methods to collect and analyse real world data are essential for the working process described above. There is a long experience of working with such methods within injury prevention in collisions, while the experience is limited for methods that address safety in driving.

For the purpose of car safety development, the analysis and data collection methods need to be flexible to ensure they provide information on existing vehicle models according to the principles of the safety development process. In general, methods that provide reliable estimates on how frequently different driver safety issues occur are needed. The term driver safety issues is used here to describe circumstances that contributed to an accident or incident explained from the drivers' perspective. In addition, analyses of real world data that provide an understanding of incident and accident causation are important. The following sections describe the need for data and available methods to collect and analyse real world data on driver behaviour.

1.2.1 The need for real world data on driver behaviour

Accidents can be regarded as rare events in relation to a large body of normal day to day traffic (Hydén 1987). In order to understand safety in driving, data from accidents, near-crashes, incidents and normal driving are important (Victor et al 2010). A few dimensions of driver behaviour relevant for real world data collection are briefly described below.

Michon (1985) described the driving task on three levels: strategic (e.g., trip planning), tactical (e.g., overtaking, obstacle avoidance) and operational (e.g., control of speed and direction). The driver can also engage in other activities besides the driving task (e.g., talking on the phone, daydreaming) that can be described according to the three task levels as well. A distinction between driving related and nondriving related attention has been used by many researchers, see for instance Regan et al (2011). Driver behaviour in accidents, near-crashes or incidents can be analysed during the pre-critical phase involving driving before the safety-critical event or during the critical phase of the event. The driver's state (e.g., stress, illness, drowsiness, and drugs) can influence safety temporarily or during whole trips, whereas personality traits (e.g., sensation seeking), experience and physical impairments are more long-term, personal factors (Petridou and Moustaki 2000). The driver is also considered as part of a system including the driver, the vehicle and the traffic environment according to the systemic view of accident causation (Hollnagel 2004).

1.3 Central methods for collecting real world data on driver behaviour

Within road safety research, real world data collection relies largely on self-report methods or observation methods. Self-report methods include for instance questionnaires, interviews, focus groups, and driving diaries (Lajunen et al. 2011). Observation methods can use video cameras or manual observers in vehicles or at the road side to analyse driver behaviour and/or interactions between road users (Hydén 1987, Hjälmdahl and Vàrhelyi 2004, Dingus et al. 2006a). These methods can be complemented with physical on-scene or in-vehicle measurements (e.g., speed, acceleration, distance) by using sensors, manual measurements, or processing of video images. Figure 2 illustrates a few central methods for real world data collection on driver behaviour, and some of these methods are further described below.

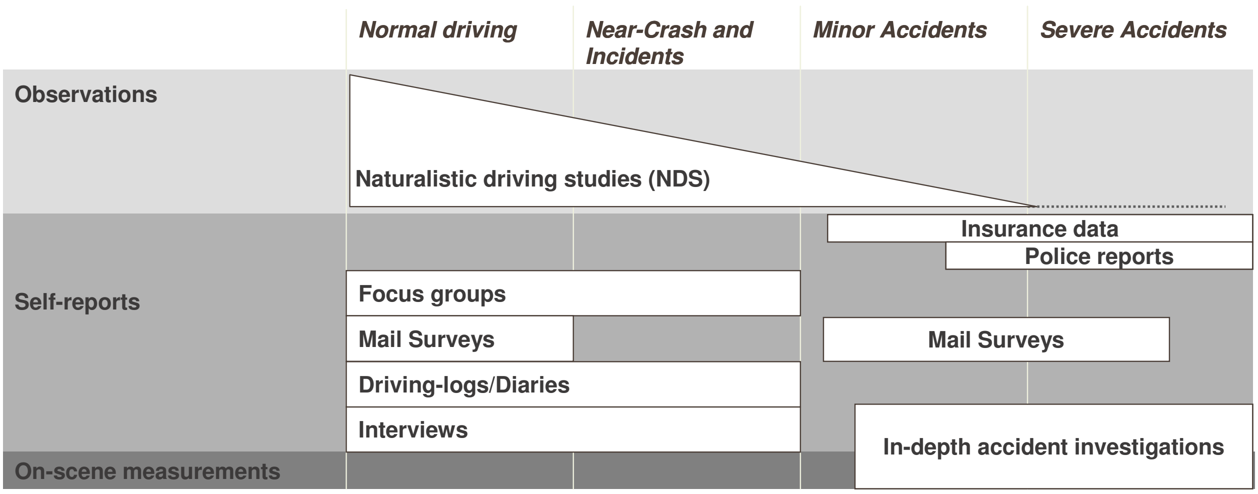

Figure 2: An overview of available methods to collect real world data on driver behaviour, and their coverage for normal driving, near-crashes/incidents, minor accidents and severe accidents.

1.3.1 Accident data collection

Accident data from in-depth investigations, police reports, insurance reports and mail surveys rely largely on self-report methods such as interviews and questionnaires. Information is provided by the involved road users and their recollection of the event is therefore crucial. Eyewitness memory is influenced by the perception of the original event, the retention of memory, and the retrieval of memory when asked about the event (Loftus 1979). Driver behaviour that is over-learned may be inaccessible in interviews (Clarke et al. 1998). According to Lajunen et al (2011) basic motor and perceptual processes are difficult to measure with self-report methods since the driver is unaware of most of the automated processes while driving. A person's memory may also be modified after the accident occurred or influenced by question wording when asked about the event (Loftus 1979).

Social desirability is another source of bias in self-reported data (af Wåhlberg et al. 2010, Lajunen et al. 2011), which can be described as "a tendency to give answers that make the respondent look good" (Lajunen et al. 2011). A distinction can be made between impression management (lying) and self-deception. Impression management tend to increase in public compared to anonymous settings, while self-deception is more linked to personality (Lajunen et al. 2011).

In-depth accident investigations

In-depth accident investigations can be used to collect detailed accident information about the pre-crash, crash and post-crash phase. Larsen (2004) described in-depth investigations performed by a multidisciplinary team that visits the scene shortly after the accident. The team collects data through interviews of the involved road users and witnesses, as well as inspecting the road environment and the involved vehicles. In-depth investigations can provide information on why the accident occurred that is difficult to obtain from other sources of accident data such as police reports (Sandin 2009). Interviews that take place on-scene shortly after the accident occurred may hold some advantages over interviews that are conducted later on when it comes to completeness and accuracy of the road users' statements. Limitations in perception, recollection of the event and social desirability can on the other hand not be ruled out. These investigations are, however, costly, and usually cover few cases with an unclear representation of the study population (Grayson and Hakkert 1988).

Police reported accidents

Police reported accident data is a widely used source for accident statistics since it is easily accessible, and covers many accidents that occur at different times of day/night in a large region, such as a country. A police officer performs the data collection by performing interviews, and by inspecting the accident scene in some cases. In many countries, the police use a form with a set of pre-defined questions that the police officer fills in (Hutchingson 1987), which allows the data to be coded in a systematic way. This data can provide general information about the vehicles, road users and environment. Written police reports can also provide more detailed information such as documented interviews. Several national accident databases contain a large number of accidents recorded by the police. Police reported data are, however, underrepresented for most types of collisions except for accidents with severe injuries, and contains limited information on accident causes (Shinar et al. 1983). Police investigations focus on legal liability, which in turn can make the involved road users reluctant to provide information that can be incriminating (Shinar et al. 1983, Clarke et al. 1998).

Insurance data on accidents
Insurance data is another source for accident statistics. Insurance companies gather mainly written insurance claim reports of the involved road users and witnesses, and codes general information about the accidents into the insurance company database. The data include information about the involved road users, the vehicles and personal injuries. Insurance data can be useful since it can provide general information on a large number of accidents that are representative and cover a broader spectrum of accidents than police reports, including damage only accidents (Hutchingson 1987, Daniels et al. 2010). Insurance data can also provide more precise information about the vehicles compared to police reported data (Hutchingson 1987). The insurance data is, however, collected some time after the accident occurred and focuses on liability for payment, which may limit the information available (Hutchingson 1987).

Accident mail surveys
Mail surveys using questionnaires is another method to collect accident data (Sagberg 1999, 2001), or more general driving behaviour (Reason et al. 1990). The strength of mail surveys is that a broad range of questions can be asked, and it can reach many persons over a wide geographical area at a low cost (Dillman 1991). Mail surveys can also include different levels of accident severity. The limitation of mail surveys is that there are several potential sources of survey error that needs to be addressed before the data can be used for statistical analysis.

According to Dillman (1991), there are four types of survey error: *sampling error*, *coverage error*, *nonresponse error* and *measurements error.* The first two sources of error are related to the sampling procedure, the number of selected units (e.g., person), and if the sampling frame covers the study population.

Nonresponse error occurs if the respondents to a survey differ systematically from the nonrespondents in a way that is important to what the survey is measuring. Response rates have declined for mail surveys in developed countries over the last decades, leading to a growing concern for nonresponse error (de Leeuw and de Heer 2002). While the most common advice to deal with nonresponse bias is to increase response rates, recent research suggests that there is no clear relationship between response rate and nonresponse bias (Groves 2006, Olson 2006). Analysing, and if necessary adjusting for nonresponse is therefore essential for survey research even if response rates are fairly high. Nonresponse analysis and adjustment is well established for mail survey research in general, but is commonly not performed when using mail surveys to collect accident data.

Finally, measurement error is related to how the respondents interpret and responds to the questions in the survey. Measurement error can be the result of poor questionnaire design or question wording (Dillman 2007). Other sources of measurement error or incomplete data is related to what the respondent is able to correctly recall, and willing to report about.

1.3.2 Driving data collection

Naturalistic driving studies (NDS)
NDS are used to collect driving data that are recorded under naturalistic conditions. The 100-cars naturalistic driving study was the first extensive NDS where 100 cars were driven in real traffic during one year (Dingus et al. 2006a). In NDS, the vehicles are equipped with unobtrusive sensors and video cameras and driven in real traffic for normal, everyday purposes. An NDS can either collect data continuously during whole trips, as was the case in the 100-cars study, or events triggered by for instance medium to hard braking (Uchida et al. 2010). NDS data usually contain video-recordings of the driver and the traffic environment, as well as a large number of time-history measurements (e.g., speed, acceleration, operational responses). A similar data collection approach is used for evaluations of advanced driver safety system (ADAS) and is then referred to as a Field Operational Test (FOT) (Victor et al. 2010). The strengths of NDS/FOT are that they can provide high resolution information on the traffic situation and road user behaviour in real traffic (Klauer et al. 2011). However, NDS/FOT can not provide any direct information on the drivers' internal processes (e.g., thoughts, planning).

1.4 Methods to analyse real world data on driver behaviour

1.4.1 Accident case studies

Case studies are widely used within different disciplines. It can be described as an approach to study singular entities where the researcher is interested in the particular rather than the general; pays attention to contextual information; use diverse sources; involves processes that take place over time; and is concerned with theory (Willig 2008). Within road safety research, case studies are common when analysing information obtained from multidisciplinary in-depth accident investigations (Sandin 2008). Several researchers have also applied a case study approach to other data sources such as police reports, interviews and questionnaires (Clarke et al. 2002).

The data from an in-depth accident investigation can be used to reconstruct the kinematic conditions and even the driver's perception and actions during the pre-crash phase. The kinematic conditions can be reconstructed by using mathematical simulations (Franck and Franck 2009). There are also methods that organise the information by structuring the events on a time axis, such as the Sequential Time Events Plotting (STEP) method (Hendrick and Benner 1987).

In-depth investigations are valuable when analysing causation in accidents that are complex by nature (Sandin 2009). Classification of accident causation is more specifically addressed with methods such as the Driver Reliability and Error Analysis Method (DREAM) (Ljung Aust 2002, Wallén Warner et al. 2008). The DREAM includes contributing factors related to the road user, the vehicles and the environment according to a systemic view of accident causation. These factors can be present shortly before the collision (sharp end failures) or long before the accident occurred (blunt end failures) (Wallén Warner et al. 2008). DREAM allows a systematic classification of critical events, contribution factors, and causal links into causation patterns.

A major concern with case studies is how to generalise the causation from individual cases to a group of accidents, and further to a large number of accidents that are representative for the population of interest. The systematic classification in DREAM allows causation patterns to be aggregated for groups of similar accidents (Sandin 2008). Since it is commonly unknown how representative causation patterns are for in-depth accident investigations, there is a need to link this data to more representative sources of accident data. Ljung (2010) suggested an approach where detailed in-depth investigations, mail survey data and large official databases are linked by using context and causation information.

1.4.2 Statistical accident analysis

Statistical accident analysis can be performed when a large number of representative cases are available. Data collected by the police, insurance companies or mail surveys are common sources for statistical analysis. The analysis can be used to describe the data (descriptive statistics), get to know the data (exploratory data analysis (EDA)), and to test what conclusions can be made from the available data (inferential statistics) (Howell 2007).

The analysis results can describe the frequency of different types of accident situations and/or safety issues involving the driver, vehicle and road environment. This is useful when prioritising different safety issues or accident types. Inferential statistics can for instance be used to calculate correlations between variables, test differences between groups, or model relationships between several variables. The quasi-induced exposure method is frequently used to estimate relative risk for different groups of drivers or activities such as mobile phone use. This method compares accident involvement for responsible and innocent drivers (Stamatiadis and Deacon 1997, Sagberg 2001). A key assumption in quasi-induced exposure is that innocent drivers resemble the distribution of all drivers exposed to accident hazard (Stamatiadis and Deacon 1997).

1.4.3 Analysis of naturalistic driving data

Safety critical events such as near-crashes and incidents from NDS can be analysed in a manner similar to accident data, since these are independent events. Selecting analysis methods for normal driver behaviour, on the other hand, require some considerations to whether the measurements are dependent or independent.

Video-recordings are important when analysing where the driver is looking, what activities s/he is engaged in, and how the traffic situations evolve. Analysing video-recordings does, however, require manual coding which requires a lot of resources (Klauer et al. 2011). In the 100-cars study, analysis of video-recordings was restricted to incidents, near-crashes, and accidents as well as randomised sequences of normal driving (Klauer et al. 2006). The selection of safety-critical events is time consuming, since it involves a process of finding appropriate kinematic triggers and evaluating events as safety-relevant or not safety-relevant by looking at video-recordings (Klauer et al. 2011). Extensive efforts are also required to assure high quality and consistency in the coded data. Virginia Tech Transportation Institute (VTTI) developed a workflow to ensure high quality in the data coded (Klauer et al. 2011). This workflow involves protocol development, data coder training, data coding, and a final review of the coded data called post-coding.

NDS data can provide information on prevalence of different contributing factors that are useful for statistical analysis. The 100-cars study identified driver inattention to the forward roadway as a contributing factor to 80% of the crashes and 65% of the near-crashes (Dingus et al. 2006a). They categorized inattention into four categories: secondary task distraction (e.g., using mobile phone, talking to passenger), driving-related inattention to the forward roadway (e.g., checking blind spots), drowsiness and nondriving related eye glances. The estimates on driver distraction are much higher in the 100-cars study compared to estimates from accident databases.

Naturalistic driving data that are continuously collected for whole trips contains what can be referred to as exposure data of driving or different type of situations. Exposure data can allow for the computation of relative accident risk of different situations (Wolfe 1982) or different types of driver behaviour. Olson et al (2009) computed odds ratios for a large number of activities performed by the drivers in a naturalistic driving study. They found for instance that text messaging increased the odds of a crash or near-crash by 23 times (OR=23.2), while talking on the phone had a protective effect (OR=0.4).

1.5. Aims

The overall aim of this thesis is to evaluate different analysis methods applied to some of the existing sources of accident and incident data in order to understand driver safety issues in accidents and incidents.

The more specific aims are to:

1. Evaluate whether statistical analysis of mail survey data is a suitable method to identify how frequently different driver safety issues occur in accidents.
2. Evaluate whether a case study approach, combining mail survey questionnaires and insurance case documents, can identify how frequently different driver safety issues occur in accidents and provide more precise information about these issues.
3. Explore the principle strengths and limitations of performing causation analysis based on event triggered video-recordings of incidents from a naturalistic driving study.

2. Summary of papers

2.1 Summary of Paper I

Nonresponse analysis and adjustment in a mail survey on car accidents.

Introduction
Statistical accident data plays an important part in car safety development. The mail survey method is popular since many persons can be reached and a wide range of questions can be posed. Low response rates have, however, raised a concern on whether mail survey estimates can be trusted as a source for making strategic decisions.

Aim
The aim of this study was to analyse and compensate for nonresponse in an accident mail survey, and to identify the most influential weighting variables.

Method
Auxiliary variables available for all mail survey recipients were retrieved from an insurance company database. Response propensity as a function of several independent variables was modelled by using logistic regression analysis. Survey weights were calculated as the inverse response probability. A split sample analysis was also performed to test how well the model would generalise to a different sample within the same population. Weighted and unweighted mail survey estimates were compared for driver drowsiness/fatigue and distraction. The correlation between the survey estimates and the auxiliary variables were also investigated to identify the most important weighting variables.

Results
Driver age, driver gender, accident type, vehicle age, ownership (private/company), and town size of where the registered owner reside influenced response propensity. Nonresponse weighting had a moderate influence on survey estimates. Driver age and accident type were the most influential weighting variables, since they were related to both response propensity and the survey variables. Driver gender and town size also had some influence, but not for all survey variables investigated.

Discussion
The findings on response propensity are in line with existing research. However, driver age had a surprisingly large effect and the results for accident type were a new finding. Weighting had a moderate effect on the survey estimates of driver distraction and drowsiness/fatigue, which is quite encouraging for the future use of accident mail surveys even when response rates are low. It is important to analyse, and if necessary compensate for, nonresponse in all survey research even when response rates are fairly high. Nonresponse analysis and adjustment can improve the confidence in survey estimates. More detailed and complete auxiliary data can improve this type of analysis in future.

2.2 Summary of Paper II

What can insurance and police reports provide in addition to mail survey variables alone when analyzing driver safety issues in accident situations?

Introduction

Traditional accident databases usually contain a large number of cases, but limited information on the driver's pre-crash behaviour. Real world accident data are important for all safety development, and both high quantity and high quality data is required for this purpose. To date, it is unknown whether there are any reasonably reliable and affordable methods to collect information on driver safety issues in accidents.

Aim

The first aim of this study was to evaluate whether a case study approach, combining mail survey data and insurance case documents, can serve as reliable sources of statistics about different driver safety issues in accident situations. The second aim was to evaluate the value of the information provided in understanding driver fatigue/drowsiness and distraction with this approach.

Method

The prevalence of three driver safety issues, low vigilance, nondriving related distraction, and driving related distraction were estimated based on mail survey variables for 977 accidents. A subset of 158 cases was randomised from the larger dataset. Additional information, mainly written descriptions by the driver and other road users from insurance case files, i.e. insurance claim reports, witness statements, a few police reports, were gathered. A case analysis was then performed, and the presence of each driver safety issue estimated. The agreement between the data sources and different road users were also analysed.

Results

Low vigilance was identified as probable or confirmed by word data in 9%, nondriving related distraction in 8%, and driving related distraction in 6% of the accidents in the case analysis. There was a good agreement between the sources when several documents were available, and the written descriptions provided valuable additional information about the driver safety issues. A clear relationship was found between survey variables and the case study results for low vigilance and nondriving related distraction. Driving related distraction was more difficult to capture.

Discussion

The estimates of the three driver safety issues were similar or lower in traditional crash databases compared to the case study results of this study. These estimates are, on the other hand, considerably higher for near-crashes and incidents in NDS studies compared to the present study. Estimates from self-reported data may be underestimated due to the role of memory and social desirability. The written descriptions can provide an understanding of some aspects of driver behaviour (e.g., loss of sleep, emotional state) that is not possible to obtain from observations alone. The findings from this study suggest that this approach may be a viable source for making safety priorities, especially if combined with other types of data such as NDS.

2.3 Summary of Paper III

Driver behaviour in car-to-pedestrian incidents: An application of the Driver Reliability and Error Analysis Method (DREAM).

Introduction

Understanding why and how safety critical situations such as accidents or incidents occur is essential for all safety development. This understanding is difficult to obtain from traditional accident investigations. NDS can, on the other hand, provide detailed information on driver behaviour. A basic premise of analysing less severe events such as incidents is that the results will partially generalise to more severe events such as accidents.

Aim

One aim of this study was to identify what video-recordings from naturalistic data can contribute when analyzing causation of safety critical events. Another aim was to evaluate whether the incident causation patterns can provide information that is useful when designing advanced driver assistance systems (ADAS).

Method

Brake triggered events were collected in a NDS in Japan. The vehicles were instrumented with video cameras that covered external views, the driver, and the foot/pedal area. Video-recordings of 90 car-to-pedestrian incidents were analysed from the drivers' perspective. DREAM was modified and used to identify the most common causation patterns. Individual causation charts were then aggregated for groups with similar car and pedestrian trajectories.

Results

Drivers frequently failed to observe the pedestrian they were in conflict with due to visual obstructions, and/or their attention was directed towards something other than the conflict pedestrian. There were also cases where the driver expected the conflict pedestrian to behave differently than s/he did. Three main groups were established based on differing causation patterns, independent of the direction of the pedestrian approach: Drivers going straight at an intersection, turning at an intersection, and going straight away from an intersection.

Discussion

The present study shows that DREAM can successfully be used for the analysis of causation in video-recordings of car-to-pedestrian incidents. The drivers' visual behaviour and activities, as well as the traffic environment were directly observable from the video-recordings. The driver’s expectations and cognitive demand, on the other hand, have to be inferred from other cues. The results show that the causation patterns can inform the design of ADAS on a conceptual level. Further time-history analysis of the video-recordings can provide more specific requirements.

There were also a number contributing factors available in the DREAM manual that were not identified in the present study. Some of these factors may be addressed by additional camera views or continuous data collection. However, there are factors that can not be collected by using video-recordings alone but require complementary methods such as interviews or diaries.

3. General discussion

The working process in car safety development (see figure 1) requires knowledge based on real world data on existing car models that can be used in product development. Methods to collect and analyse real world data are required for this purpose. The experience in using such methods to collect and analyse driver behaviour is, however, limited. Detailed data is needed to understand why accidents and incidents occur, and representative data is needed to identify how frequently different safety issues occur. This work investigates accident mail survey questionnaires, insurance documents and video-recorded incidents from a NDS for the purpose of car safety development.

3.1 Using a mail survey to estimate how frequently different driver safety issues occur in accidents

The mail survey method is a cost efficient method to gather statistical data that can reach a large number of persons and include a wide range of questions (Dillman 2007). Before using an accident mail survey as a source for prioritising driver safety issues, however, different sources of survey error have to be considered.

Sampling and coverage error are quite straightforward and can be avoided by using appropriate procedures for selecting survey recipients, and deviations from ideal conditions are possible to control for. Nonresponse error, on the other hand, is rarely accounted for in accident mail surveys. The results from Paper I revealed that the survey estimates for driver distraction and drowsiness/fatigue were only moderately affected when inverse response propensity weights were applied to the survey data. The results are encouraging when using mail surveys as a source for accident statistics on driver behaviour. Even though these results are promising, it is important to keep in mind that nonresponse analysis and adjustment can only be accounted for by those variables that are available for all mail recipients. There may be other factors that are important for response propensity, such as personality, that is typically not available as auxiliary data.

Concerning measurement error, self-reported accident data is restricted to what the driver is able to accurately recall and willing to report. The mail survey questionnaires used in Paper I and II are treated anonymously, which is one factor that favours less socially desirable responding (Lajunen and Summala 2003). It is, however, difficult to assess the influence of social desirability and recall bias without having access to other sources of information. Lajunen et al (2011) suggest to emphasize anonymity in mail surveys, including addition scales (e.g., social desirability, lie scales, etc.) and objective measures (e.g., observations of accidents and driver behaviour) to balance against social desirability responding.

Consequently, mail surveys can be used to gather general information for a large number of accidents that can be used to prioritise different types of accidents. Mail surveys can also provide estimates on the prevalence of some driver safety issues in accidents. These may, however, be underestimated due to the role of memory and social desirability which is difficult to control for. It may therefore be advisable to use additional data sources such as NDS to estimate the prevalence of different driver safety issues.

3.2 The value of document case studies to study driver safety issues in accidents

The results from Paper II showed that the written descriptions in mail survey questionnaires and insurance case documents can provide additional valuable information about driver safety issues in accident situations compared to using mail survey variables alone. This analysis can also help interpreting multiple choice questions in the mail survey, providing more specific explanations and identify driver safety issues that are not captured by the survey. This type of analysis can also point out areas of improvement for the questionnaire's design. Cases where detailed descriptions were provided by the involved road users also contained valuable additional information about the driver safety issues analysed.

Estimates on how frequently different driver safety issues occur in accidents may also be improved by analysing written descriptions in a manner similar to Paper II. This is, however, restricted to information that the driver is able and willing to report about. The results presented in Paper II indicated that driving related visual search behaviour was difficult to capture with written descriptions in the mail survey questionnaire and insurance documents. One explanation is that visual search is largely automated behaviour that is difficult to record with self-report methods according to Lajunen et al (2011). Naturalistic data may instead be useful when studying this type of behaviour.

The data in Paper II does, however, not provide sufficient information on the influence of social desirability nor driver's recollection of the accident. Consequently, the estimated prevalence of distraction and low vigilance may be underestimated. Alcohol related accidents may be especially vulnerable to social desirability (Lajunen and Summala 2003). Police reports may be a better source for this safety issue, since this is commonly measured by the police at the scene of the accident. Cases where descriptions from the driver and other involved road users are available can provide a basic check on survey validity. In many of the cases there was, however, no additional information available from other persons besides the responding driver, which was especially pronounced for single vehicle collisions.

Hence, mail surveys combined with documents from the insurance company and police reports can be viable sources for car safety development. The main contribution from this approach is the additional information provided by the written descriptions of the accident, which is useful when describing accident scenarios used when formulating vehicle requirements. The information on the validity of survey estimates on driver safety issues is, however, somewhat restricted. This approach may therefore be best suited to provide a better understanding of the nature of the driver safety issues that are possible to capture with self-report methods.

3.3 Incident causation analysis based on video-recorded data

The results from Paper III demonstrated that the incident analysis of video-recorded naturalistic driving data can provide a detailed description of incident causation that includes the road environment, other road users' behaviour, and the visual and operational behaviour of the driver. Cognitive demand, on the other hand, has to be interpreted from other cues such as complexity of the traffic situation and/or tasks performed by the driver. In addition, some factors related to the expectancy of the other road users' behaviour require knowledge about the local traffic rules and culture, and what can be considered normal behaviour. Driver traits (e.g., sensation seeking), driver states (e.g., fatigue) and strategic circumstances (e.g., time pressure) are difficult to obtain from short video sequences alone, but may require data from other data collection methods such as interviews or diaries.

Using continuous video-recordings for whole trips, instead of only triggered events can address some of these shortcomings but will not tell the whole story. Longer video-sequences could for instance enable identification of driver drowsiness or fatigue (Dingus et al. 2006b). Paper III highlights the advantages of observing driver behaviour under naturalistic driving conditions, and the aspects of driver behaviour that is not or only partly captured in self-reported data. This may be especially true for highly automated behaviours that are over-learned (Lajunen et al. 2011). The naturalistic driving data can be seen as a source that complements accident investigations, since it can improve the understanding of driver safety issues, but can not provide an understanding of all aspects of safety in driving. NDS generally contains few accidents, and incidents can be studied as a surrogate for accidents. Incident analysis can provide an understanding of why the driver ends up in safety critical situations, and how these situations are resolved. The assumption that incidents will partially generalise to accidents is quite reasonable, but it is not exactly known to what extent these events are related.

The 100-cars study was the first study to identify how frequently different contributing factors occurs in accidents, near-crashes and incidents (Dingus et al. 2006a). Paper III is, on the other hand, the first study to demonstrate how contributing factors can form causation patterns based on video-recordings from a NDS. Analysing causation can provide an understanding about the incident and accident mechanisms. This understanding is useful in car safety development when choosing principles for countermeasures that aim to support the driver in these situations.

3.4 Implications of the results

The results presented in this thesis imply that self-reported and observation data collection approaches are both needed as complementary sources of information for car safety development. Observations in naturalistic driving studies can provide an understanding of driver safety issues that are inaccessible from self-report methods such as mail surveys. Observational techniques can on the other hand provide detailed descriptions of the traffic situation, the behaviour of other road users, as well as the drivers' visual behaviour and activities. Self-reported data are for several reasons still valuable in its own right. Firstly, NDS usually contain a limited number of accidents, and data from other sources are required to understand how observed events such as near-crashes and incidents are related to accidents. Secondly, self-reported data provide insights into how the driver experienced the situation, as opposed to a person who interprets the situation while analysing video-recordings. The drivers' perspectives are important when designing products focused on user needs. The drivers' own descriptions can in some cases capture strategic circumstances (e.g., lack of sleep, time pressure) or driver state (e.g., daydreaming) that may be difficult to observe in video-recordings.

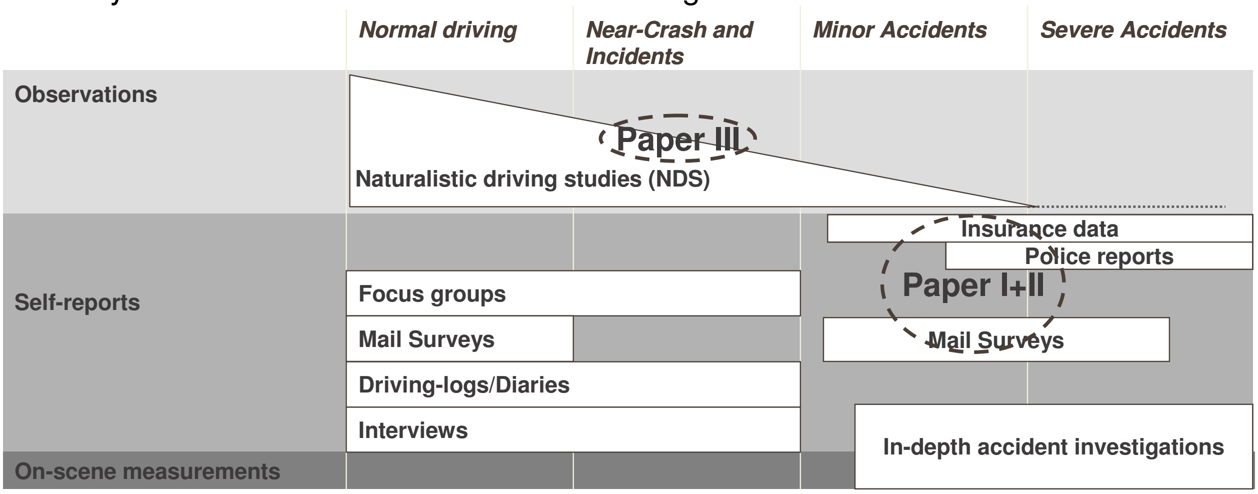

Figure 3: Paper I-III in relation to available data collection methods of real world data on driver behaviour.

Paper I and II have contributed to a better understanding of the validity of accident mail surveys when studying driver behaviour. Mail surveys can be used in the future to collect general context information on a large number of accidents provided that appropriate procedures are used for selecting mail survey recipients and controlling for survey nonresponse. Mail surveys can also be used to gather information about the driver safety issues that the driver is able and willing to report about. Paper I and II have demonstrated that mail surveys and document case studies can increase the level of information about these driver safety issues. Paper III also showed that NDS can provide in-depth understanding of several aspects of causation of safety critical events such as incidents. This is especially valuable for aspects of driver behaviour that is difficult to capture with self-report methods. The causation analysis in Paper III could also be complemented with a time-history analysis of driver behaviour and the kinematics of the involved road users that in turn can prove valuable in the formulation of car safety requirements.

3.5 Future research

For future studies, there are some opportunities for improvement when collecting and analysing real world data on driver behaviour. Improved knowledge about the link between incidents and accidents can provide an understanding of how findings from incident studies can generalise to accidents. For accident mail surveys, the validity needs to be further addressed when considering the role of the drivers' memory and social desirability.

In the future, the validity of accident mail surveys can be further improved if the mail survey data can be checked against other sources of information, besides insurance case documents. These sources can for instance be event data recorders (EDR) or NDS. A possibility to facilitate the analysis of mail survey data is to store text from open ended questions in survey databases. This could enable advanced search algorithms on larger datasets. Using on-line web surveys can provide written text that is directly accessible for analysis after the questionnaire is filled in, saving time and effort since there is no need to manually transcribe text. The influence on flexibility in explaining the accident situation as well as different sources of survey error have to be considered before changing survey mode (Dillman 1991).

Furthermore, in-depth analysis of specific driver safety issues may be performed by combining several data collection methods such as NDS, mail surveys, on-scene accident investigations, document case studies and EDR. Mail survey variables can be used for statistical analysis, and to select accidents for further document case analysis and/or interviews. Naturalistic driving data can also be analysed with respect to the presence and consequences of a driver safety issue in normal driving as well as in safety critical situations. A combination of different data sources could possibly also provide a better understanding of the link between accidents, near-crashes and incidents.

4. Conclusions

The present thesis investigates what self-reported and observation data can provide about driver safety issues in safety critical situations. The data sources investigated are accident mail survey data, insurance data, police reports and event triggered video-recordings of incidents from an NDS.

A mail survey can be used as a source for statistical accident data on different driver safety issues. Some safety issues may, however, be underestimated due to the role of memory and social desirability that is difficult to control for. Prerequisites for using mail surveys for statistical data are appropriate sampling procedures and a sample frame that covers the study population. Performing a nonresponse analysis, and if necessary weighting, is also advisable even if response rates are fairly high.

Driver safety issues in accident situations can be further studied by using a case study approach where a mail survey questionnaire and insurance case documents are combined. This can help interpreting responses to multiple choice questions, and to identify issues that are not captured by the survey variables. Both the estimates as well as more in-depth understanding of issues that the driver is able and/or willing to report about can be improved. The survey and insurance documents do, however, provide very little insight to the influence of the drivers' memory and social desirability.

Event triggered video-recordings of incidents from NDS can provide information on the drivers' visual behaviour, driving tasks, the road environment and other road users' behaviour that is directly observable. Cognitive demand and expectancy of other road users' behaviour, on the other hand, relies on the analyst's interpretation. Driver states, traits and strategic circumstances are, however, difficult or impossible to assess with short video-recorded sequences. Some, but not all, of these issues may be addressed by collecting data from whole trips. NDS can provide valuable knowledge about driver behaviour in safety critical situations, especially for information that is inaccessible with self-reports.

The general conclusion from this work is that both self-reported and observation data are required to understand driver safety issues in safety critical situations. Observational techniques (e.g., video-recordings) can provide information that is difficult for the driver to recall or is unwilling to report about. Self-report methods, such as mail surveys, can be used as a cost efficient method to collect information from a large number of accidents on general accident circumstances, how the driver experienced the situation, and capture issues that are not observable (e.g., lack of sleep, time pressure).

In the future, statistical analysis from accident mail surveys may be further validated by using information from vehicle pre-crash recorders or NDS. Several data sources may be combined for in-depth analysis of different driver safety issues. NDS may, for instance be combined with interviews, diaries or mail surveys. Future research should also address the link between accidents, near-crashes and incidents. A better understanding of this relationship will improve the understanding of how incident causation will generalise to accident causation.

References

af Wåhlberg, A.E., Dorn, L., Kline, T., 2010. The effect of social desirability on self reported and recorded road traffic accidents. Transportation Research Part F: Traffic Psychology and Behaviour 13 (2), 106-114.

Almqvist, R., Mellander, H., Koch, M., 1982. Frontal crash protection in a modern car concept. Proceedings of the 9th International ESV Conference. Kyoto, pp. 154-163.

Clarke, D.D., Ward, P., Truman, W., 2002. In-depth accident causation study of young drivers. TRL Report TRL542. Road Safety Division, Department for Transport, Local Government and the Regions. Retrieved from the internet on the 20th of April 2012. http://www.trl.co.uk/online_store/reports_publications/trl_reports/cat_road_user_safety/report_in-depth_accident_causation_study_of_young_drivers.htm

Clarke, D.D., Forsyth, R., Wright, R., 1998. Behavioural factors in accidents at road junctions: The use of a genetic algorithm to extract descriptive rules from police case files. Accident Analysis & Prevention 30 (2), 223-234.

Corben, B.F., Logan, D.B., Fanciulli, L., Farley, R., Cameron, I., 2010. Strengthening road safety strategy development 'towards zero' 2008-2020 - Western Australia's experience scientific research on road safety management SWOV workshop 16 and 17 November 2009. Safety Science 48 (9), 1085-1097.

Daniels, S., Brijs, T., Keunen, D., 2010. Official reporting and newspaper coverage of road crashes: A case study. Safety Science 48 (10), 1469-1476.

de Leeuw, E., de Heer, W., 2002. Trends in household survey nonresponse: A longitudinal and international comparison. In: Survey nonresponse. Groves, R.M., Dillman, D.A., Eltinge, J.L., Little, R.J.A. eds. Wiley, New York, pp. 41-54.

Dillman, D.A., 1991. The design and administration of mail surveys. Annual Review of Sociology. (17), 225-249.

Dillman, D.A., 2007. Mail and internet surveys: The tailored design method. Wiley, Hoboken, N.J.

Dingus, T.A., Klauer, S.G., Neale, V.L., Petersen, A., Lee, S.E., Sudweeks, J., Perez, M.A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z.R., Jermeland, J., Knipling, R.R., 2006a. The 100-car naturalistic driving study, phase II – Results of the 100-car field experiment. Report no: HS 810 593. NHTSA DOT.

Dingus, T.A., Neale, V.L., Klauer, S.G., Petersen, A.D., Carroll, R.J., 2006b. The development of a naturalistic data collection system to perform critical incident analysis: An investigation of safety and fatigue issues in long-haul trucking. Accident Analysis & Prevention 38 (6), 1127-1136.

Elvebakk, B., Steiro, T., 2009. First principles, second hand: Perceptions and interpretations of vision zero in Norway. Safety Science 47 (7), 958-966.

Erke, A., 2008. Effects of electronic stability control (ESC) on accidents: A review of empirical evidence. Accident Analysis & Prevention 40 (1), 167-173.

Eugensson, A., Ivarsson, J., Lie, A., Tingvall, C., 2011. Cars are driven on roads, joint visions and modern technologies stress the need for co-operation. The 22nd ESV Conference. Washington, DC.

Evans, L., 1999. Antilock brake systems and risk of different types of crashes in traffic. Journal of Crash Prevention and Injury Control 1 (1), 5-23.

Franck, D., Franck, H., 2009. Mathematical methods for accident reconstruction - A forensic engineering perspective. CRC Press, Taylor & Francis Group. ISBN 978-1-4200-8897-7

Grayson, G.B., Hakkert, A.S., 1987. Accident analysis and conflict behaviour. In: Road users and traffic safety. Rothengatter, J.A., De Bruin, R.A. eds.Van Gorkum Publishers, the Netherlands.

Groves, R.M., 2006. Nonresponse rates and nonresponse bias in household surveys. Public Opinion Quarterly 70 (5), 646-675.

Hendrick, K., Benner, L., 1987. Investigating accidents with STEP. Marcel Dekker Inc., New York.

Hjälmdahl, M., Vàrhelyi, A., 2004. Validation of in-car observations, a method for driver assessment. Transportation Research Part A: Policy and Practice 38 (2), 127-142.

Hollnagel, E., 2004. Barriers and accident prevention. Ashgate Publishing, Burlington, VT, USA. ISBN:0-7546-4301-8

Howell, D.C., 2007. Statistical methods for psychology, International Student Edition, Sixth edition ed. Thomson Wadsworth, Belmont, CA, USA.

Hutchingson, T.P., 1987. Road accident statistics. Rumsby Scientific Publishing, Adelaide, Australia.

Hydén, C., 1987. The development of a method for traffic safety evaluation: The Swedish traffic conflict technique. Bulletin 70. Lund University, Lund, Sweden.

Isaksson-Hellman, I., Norin, H., 2005. How thirty years of focused safety development has influenced injury outcome in Volvo cars. 49th Annual Proceedings Association for the Advancement of Automotive Medicine (AAAM). Boston, USA, pp. 63-77.

Jakobsson, L., Lindman, M., Svanberg, B., Carlsson, H., 2010. Real world data driven evolution of Volvo cars' side impact protection systems and their effectiveness. 54th AAAM Annual Conference Annals of Advances in Automotive Medicine. pp. 127–136.

Jakobsson, L., Norin, H., 2004. AIS1 neck injury reducing effect of WHIPS (whiplash protection system). Proceedings of the IRCOBI Conference. Graz, Austria, pp 297-305.

Johansson, R., 2009. Vision zero - implementing a policy for traffic safety. Safety Science 47 (6), 826-831.

Klauer, S.G., Dingus, T.A., Neale, V.L., Sudweeks, J.D., Ramsey, D.J., 2006. The impact of driver inattention on near-crash/crash risk: An analysis using the 100-car naturalistic driving study data. Report No. DOT HS 810 594.

Klauer, S.G., Perez, M., Mcclafferty, J., Bryan, E.P., 2011. Chapter 6 - Naturalistic driving studies and data coding and analysis techniques. In: Handbook of traffic psychology. Academic Press, San Diego, pp. 73-85.

Korner, J., 1989. A method for evaluating occupant protection by correlating accident data with laboratory test data. SAE Technical Paper 890747.

Lajunen, T., Summala, H., 2003. Can we trust self-reports of driving? Effects of impression management on driver behaviour questionnaire responses. Transportation Research Part F: Traffic Psychology and Behaviour 6 (2), 97-107.

Lajunen, T., Özkan, T., Bryan, E.P., 2011. Chapter 4 - Self-report instruments and methods. In: Handbook of traffic psychology. Academic Press, San Diego, pp. 43-59.

Larsen, L., 2004. Methods of multidisciplinary in-depth analyses of road traffic accidents. Journal of Hazardous Materials 111 (1-3), 115-122.

Lindman, M., Tivesten, E., 2006. A method for estimating the benefit of autonomous braking systems using traffic accident data. SAE technical paper 2006-01-0473. SAE 2006 World Congress Exhibition.

Ljung Aust, M., 2002. DREAM– Driving Reliability and Error Analysis Method. Master Thesis, ISRN: LIU-KOGVET-D-02/16-SE, Department of Computer and Information Science (IDA), Linköping University, Linköping, Sweden.

Ljung Aust, M., 2010. Generalization of case studies in road traffic when defining pre-crash scenarios for active safety function evaluation. Accident Analysis & Prevention 42 (4), 1172-1183.

Loftus, E.F., 1979. Eyewitness testimony. Harward University Press, Cambridge, Massachussets, London, England.

Michon, J.A., 1985. A critical view of driver behaviour models: What do we know, what should we do? In: Human behaviour and traffic safety. Evans, L., Schwing, R.C. eds. Plenum Press, New York, pp. 485-520.

Norin, H., 2010. Field data - A base for the development of safe vehicles. Proceedings of the IRCOBI Conference. Hanover , Germany, pp. 3-14.

Olson, K., 2006. Survey participation, nonresponse bias, measurement error bias, and total bias. Public Opinion Quarterly 70 (5), 737-758.

Olson, R.L., Hanowski, R.J., Hickman, J., Bocanegra, J., 2009. Driver distraction in commercial vehicle operations. Technical report FMCSA-RRR-09-042. Retreived from the internet on the 1st of April 2012. http://www.distraction.gov/research/PDF-Files/Driver-Distraction-Commercial-Vehicle-Operations.pdf

Peden, M., Scurfield, R., Sleet, D., Mohan, D., Hyder, A.A., Jarawan, E., Mathers, C., 2004. The world report on road traffic injury prevention. World Health Organization, Geneva. Retreived from the internet on the 29th of April 2012. http://whqlibdoc.who.int/publications/2004/9241562609.pdf

Petridou, E., Moustaki, M., 2000. Human factors in the causation of road traffic crashes. European Journal of Epidemiology 16 (9), 819-826.

Reason, J.T., Manstead, A.S.R., Stradling, S.G., Baxter, J.S., Campbell, K., 1990. Errors and violations on the road: A real distinction? Ergonomics 33(10-11), 1315–1332.

Regan, M.A., Hallett, C., Gordon, C.P., 2011. Driver distraction and driver inattention: Definition, relationship and taxonomy. Accident Analysis & Prevention 43 (5), 1771-1781.

Sagberg, F., 1999. Road accidents caused by drivers falling asleep. Accident Analysis & Prevention 31 (6), 639-649.

Sagberg, F., 2001. Accident risk of car drivers during mobile telephone use. International Journal of Vehicle Design 26 (1), 57-69.

Sandin, J., 2008. Aggregating case studies of vehicle crashes by means of causation charts. Ph.D. Thesis. Chalmers University of Technology, Gothenburg, Sweden. ISBN/ISSN: 978-91-7385-168-8

Sandin, J., 2009. An analysis of common patterns in aggregated causation charts from intersection crashes. Accident Analysis & Prevention 41 (3), 624-632.

Shinar, D., Treat, J.R., Mcdonald, S.T., 1983. The validity of police reported accident data. Accident Analysis & Prevention 15 (3), 175-191.

Stamatiadis, N., Deacon, J.A., 1997. Quasi-induced exposure: Methodology and insight. Accident Analysis & Prevention 29 (1), 37-52.
Uchida, N., Kawakoshi, M., Tagawa, T., Mochida, T., 2010. An investigation of factors contributing to major crash types in Japan based on naturalistic driving data. IATSS Research 34 (1), 22-30.
UN, 2010. Global plan for the decade of action for road safety 2011-2020. United Nation. Retreived from the internet on the 29th of April 2012. http://www.who.int/roadsafety/decade_of_action/plan/plan_en.pdf
Wallén Warner, H., Björklund, G., Johansson, E., Ljung Aust, M., Sandin, J., 2008. DREAM 3.0: Documentation of references supporting the links in the classification scheme report. Chalmers University of Technology, Gothenburg, Sweden.
WHO, 2009. Global status report on road safety. Time for action. World Health Organisation. Retrieved from the internet on the 15th of November 2011. http://whqlibdoc.who.int/publications/2009/9789241563840_eng.pdf
Victor, T., Bärgman, J., Hjälmdahl, M., Kircher, K., Svanberg, E., Hurtig, S., Gellerman, H., Moeschlin, F., 2010. Sweden-Michigan Naturalistic Field Operational Test (SeMiFOT) phase 1: Final report. SAFER Report 2010:02, Project C3 SeMiFOT. Retrieved from the internet on the 5th of April 2012. https://document.chalmers.se/download?docid=1773834060
Willig, C., 2008. Case studies. In: Introducing qualitative research in psychology. pp. 74-91. Open University Press, Berkshire, England. ISBN10:0-335-22115-7
Wolfe, A.C., 1982. The concept of exposure to the risk of a road traffic accident and an overview of exposure data collection methods. Accident Analysis & Prevention 14 (5), 337-340.