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Topics and applications of previous and current naturalistic driving studies

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Authors: Agathe Backer-Grøndahl (TØI), Ross Phillips (TØI), Fridulv Sagberg (TØI), Katerina Touliou (CERT-HIT), Michael Gatscha (TTI)

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1	SWOV Institute for Road Safety Research (project co-ordinator)	NL
2	CERTH/HIT Hellenic Institute of Transport	GR
3	KfV Kuratorium für Verkehrssicherheit	A
4	Loughborough University	UK
5	Or Yarok	ISR
6	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek - TNO	NL
7	TØI Institute of Transport Economics	NO
8	Test and Training International Planning and Service GmbH	A
9	Universitat de València	ES

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Abstract

In order to identify previous and current research topics and applications within the field of naturalistic driving observation, a literature review was conducted and the main results are presented in the present document. This report provides an extensive overview of studies and projects applying naturalistic driving within road traffic research, and all studies included are discussed and summarised in a concise and accessible way. First, naturalistic driving observation as a method for investigating road safety issues is discussed and compared to other more traditional methods like experiments and epidemiological studies. Second, the scientific literature on naturalistic driving is presented and discussed in relation to various topics and applications. Included literature covers peer reviewed articles/papers, published reports and unpublished material. The main areas in which naturalistic driving observation has been studied and applied are ‘driver distraction and inattention’, ‘driver drowsiness and fatigue’, ‘heavy vehicle – light vehicle interaction’, ‘driver characteristics and states’ and ‘applied use of naturalistic driving observation’. However, naturalistic driving observation should be applied in other areas as well, and by using this method we can gain new and more valid insights in road safety as well as eco-driving and traffic management.

This report serves as a basic framework for further exploring and developing naturalistic driving observation within the field of road user behaviour research.

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Executive Summary

What is naturalistic driving observation?

Naturalistic driving observation is a method by which one can objectively observe various driver and crash related behaviour. More specifically, naturalistic driving observation includes objectively and unobtrusively observing normal drivers in their normal driving context while driving their own vehicles. Typically, participants get their own vehicles equipped with some sort of data logging device that can record various driving behaviours such as speed, braking, lane keeping/variations, acceleration, deceleration etc., as well as one or more video cameras. Optimally, this allows for observation of the driver, vehicle, road and traffic environments and interaction between these factors.

What is PROLOGUE?

PROLOGUE stands for **PRO**moting real **L**ife **O**bservation for **G**aining **U**nderstanding of road user behaviour in **E**urope. The main objective of PROLOGUE is to demonstrate the usefulness, value, and feasibility of conducting naturalistic driving observation studies in a European context in order to investigate traffic safety of road users, as well as other traffic related issues such as eco-driving and traffic flow/traffic management. This report is a literature review documenting previous and current research topics and applications within the field of naturalistic driving.

The main objectives of the present report are:

1) To discuss naturalistic driving observation and compare this method to other more traditional methods for studying driver behaviour and crashes

2) To review and discuss the literature on naturalistic driving observation.

Why naturalistic driving observation?

Naturalistic driving observation is a relatively new method for studying road safety issues, and in order to answer the question of “why” this method should be used in future studies, three guiding questions serve as a framework:

- Can naturalistic driving observation as a method alleviate the challenges and problems associated with more traditional methods?
- How does naturalistic driving observation contribute over and above other research methods for studying traffic safety and behaviour?
- What are the weaknesses of naturalistic driving observation?

The golden standard for studying *driving behaviour* is highly controlled experiments, most often simulator experiments. The main advantage of controlled experiments is that one observes behaviour directly, and has strict control over potentially confounding variables, which in turn allows for causal explanations. On the other hand, controlled experiments are most often conducted in artificial study settings and generalisation of the results is questioned. Driving behaviour is also often studied by means of self-report questionnaires and validated question batteries. As with all self-report measures, these measures can be subject to various biases and errors.

Epidemiological research on *crashes* is most often based on crash data bases and/or police or insurance company data. Information gained from such databases is based on real crashes, and the sample sizes are large as such studies aim at giving information about crashes on a population level. However, the information about the crash reflects the information that is available for the police or the insurance company or other party that records or gathers the data, and the information available may be insufficient. Moreover, observation of variables of interest is indirect (i.e., crashes and related behavioural and characteristic variables are not directly observed), and one cannot rule out errors and biases in the recording of the data. Finally, not all crashes are reported or investigated, precluding a large amount of potentially interesting crash data.

Naturalistic observation of driving behaviour allows for observing behaviour directly in a realistic context as drivers are observed in their everyday driving. Thus, the problem of the artificial study setting associated with experiments is alleviated. Also, observation of behaviours and factors leading to an incident or crash is observed, allowing for some interpretation of causality. However, as one does not have control over confounding variables as in experiments, conclusions about causality are limited at best. As for studying crashes, the main advantage of analysing crashes/near-crashes by means of naturalistic driving observation is of course the direct observation of driver behaviours and - depending on the technical equipment - environmental factors as well as road and traffic variables, preceding the event in question. Thus, assuming one has a large sample, naturalistic driving observation studies allow for investigating crashes both quantitatively and qualitatively.

Importantly, though, naturalistic driving observation must be recognised as a method that requires heavy resources in terms of samples, duration, data gathering, data storage, data reduction, and analysis.

What topics can be addressed when using naturalistic driving observation?

In PROLOGUE the main focus is on *road safety* and the potential of naturalistic driving observation as a tool for gaining new and more valid knowledge about *road user behaviour*. Importantly, in all fields in which one strives for understanding the interaction between the driver, vehicle, road and environment, naturalistic driving observation may turn out to be the best research method, although heavy on resources.

Although the method is relatively new, research using naturalistic driving observation has been conducted in various fields the last decade. In particular driver distraction and inattention have been studied quite extensively by use of naturalistic driving observation, and new and invaluable knowledge has been gained regarding relative risks and population attributable risks. Also, ‘driver drowsiness’, ‘lane-change behaviour’, ‘interaction between heavy and light vehicles’ and ‘ driver characteristics’ are topics that have been investigated by use of naturalistic driving observation. Another promising potential of naturalistic driving observation concerns application of such observation of and feedback to drivers during driver training. All these areas would gain from further research using this method. ‘In-vehicle systems’ is another area that has been studied to a lesser degree in pure naturalistic studies. However, in-vehicle system are tested and investigated in large scale in field operational tests (FOTs).

Naturalistic driving observation is also particularly promising with regard to investigating environmental factors such as road, infrastructure, and traffic conditions, and their effect on road user behaviour, as well as the interaction between drivers, vehicle and the environment.

Taking a more scientific perspective, naturalistic driving observation also allows for investigation and validation of other more traditional methods for studying road user behaviour, such as self-report measures.

In addition to the fields listed above that all concern road safety, other areas may gain from being studied by using naturalistic driving observation as well. Such areas could for instance be eco-driving and traffic flow studies.

1 Introduction

The main objective of PROLOGUE is to demonstrate the usefulness, value, and feasibility of conducting naturalistic driving observation studies in a European context in order to investigate traffic safety of road users, as well as other traffic related issues such as eco-driving and traffic flow/traffic management. Several approaches will be used in order to prove the value, usefulness and feasibility of this method:

- Literature review (WP1)
- Communication with potential user groups (WP1/WP5)
- Review of methodological/technical/ethical considerations (WP2)
- Small scale field trials (WP3)

1.1 PROLOGUE Task 1.1

As part of the PROLOGUE project, a literature review was conducted in order to investigate previous and current studies using naturalistic driving observation as a method. In this report, main findings from the literature review will be presented and discussed. Focus will be on areas that have been and can be studied by means of naturalistic driving, how it has been studied, main results, and potential for further research. First, however, naturalistic driving observation will be described and discussed in relation to other more traditional approaches to investigate traffic safety issues such as driver behaviour and crashes. Finally, abstracts of reviewed papers will be presented in the appendices (Appendix I, II and III), as well as an overview of research field and topics that has been addressed using naturalistic driving observation (Appendix IV).

Thus, the main objectives of the present report are:

1) To discuss naturalistic driving observation and compare this method to other more traditional methods for studying driver behaviour and crashes

2) To review and discuss the literature on naturalistic driving observation.

Within PROLOGUE it will first and foremost be focused upon naturalistic observation as a method to study traffic safety issues. However, naturalistic observation allows for studying other traffic related areas as well. Consequently, the potential for using naturalistic driving observation for studying traffic management/traffic flow and eco-driving will also be touched upon in the project in general, and this document in particular. In addition, site-based naturalistic observation, allowing for observation of the traffic picture including interaction between motorised vehicles and vulnerable road users will be discussed briefly.

1.2 What is naturalistic driving observation?

Naturalistic driving observation is a method by which one can objectively observe various driver- and crash-related behaviour. More specifically, naturalistic driving observation includes unobtrusively observing normal drivers in their normal driving context while driving their own vehicles. Typically, participants get their own vehicles equipped with some sort of data logging device that can record various driving behaviours such as speed, braking, lane keeping/variations, acceleration, deceleration etc., as well as one or more video cameras (McLaughlin, Hankey et al. 2009). In order to investigate crashes, near-crashes and critical incidents, kinematic triggers are defined and the behaviour of the driver prior to and during the crash can easily be observed in retrospect.

It has been proposed that naturalistic studies can be classified into three basic types of studies; 1) baseline/normative/exposure studies where the aim is to investigate driving behaviour and performance per se, 2) critical incident/near-crash studies where the main aim is to characterise and investigate such incidents and 3) system-focused studies where the aim is to study the driver's interaction with in-vehicle systems (Llaneras, Freedman et al. 1999). This is a useful categorization, even though studies of type 2 should include actual crashes as well as critical incidents and near-crashes, and investigation of behaviour leading to these events should be of main interest. Within PROLOGUE all three types of studies will be covered with regard to literature reviews and potential for further research and proposed research questions. However, studies of type 3 focusing on the driver's interaction with various in-vehicle systems will only be covered to the extent that it is the driver and her or his performance that is of main interest, not the in-vehicle system in question. Thus, field operational tests (FOT) conducted to investigate various in-vehicle support systems will only be covered to a limited degree[1].

Summing up, in task 1.1 of PROLOGUE the main aim is to summarize and investigate potential areas for studying a) drivers' behaviour and b) crashes, near-crashes and critical incidents as well as factors leading to such events, by means of naturalistic observation.

[1] For further information about the distinction between FOTs and NDs, see section 2.1.1.

2 Methods for studying traffic behaviour and accidents

In this chapter, methods for studying and analysing driving behaviour, as well as crashes and behaviour leading to crashes, will be discussed. In particular, more traditional research methods such as controlled experiments and epidemiological studies will be scrutinized in terms of their strengths and weaknesses, and subsequently compared to naturalistic driving observation. The following questions serve as a framework for this discussion:

- Can naturalistic driving observation as a method alleviate the challenges and problems associated with more traditional methods?
- How does naturalistic driving observation contribute over and above other research methods for studying traffic safety and behaviour?
- What are the weaknesses of naturalistic driving observation?

2.1 Studying driver behaviour by means of traditional methods

Driver behaviour research is important with regard to understanding how different groups of people drive in different situations, and to some degree why they drive as they do. Various research methods and designs can be used in order to measure driving behaviour of various drivers in different situations. According to McLaughlin et al. (2009) the most common methods for studying driving behaviour and performance can be placed on a continuum in which “experimental control” and “external validity” are the variables that define the continuum; at one end are controlled experiments with low external validity (typically simulator experiments), while studies without any control of external variables and higher external validity are placed at the other end (typically naturalistic studies). This continuum will be adopted in the present section where we discuss methods in which driving behaviour is observed directly. However, we will also discuss self-report studies, in which behaviour is measured indirectly.

2.1.1 Direct observation of driving behaviour

Methods and study designs in which driving behaviour is observed directly in one way or another is discussed in the present section. To a large degree, this section is based upon the article of McLaughlin et al. (2009).

Controlled experiments/simulator experiments. Controlled experiments are in many respects the golden standard for investigating behaviour, and with regard to driving behaviour, simulator experiments are widely used and appreciated. The main advantage of experimental research is that the researchers have strict control over potential external confounding variables, making it possible to isolate the effect the experimenter is interested in, e.g., the effect of talking on mobile phone on lateral position variability. This means that there is high internal validity. The experimental control that defines experiments allows for making causal explanations, i.e., explanation about X (the experimental variable) leading to Y (the driving behaviour in question), and this is the main reason why experiments are so highly appreciated.

The main downside of having control over all variables except the experiment variable is that the experimental setting most often is artificial. This is particularly true for simulator experiments, even though efforts are constantly made to build and apply high fidelity simulators. Thus, the ecological validity[2] of the experiment is low, making generalisation to real-world driving difficult.

Another limitation associated with experiments concerns another part of the external validity, namely that of generalising the results from a limited sample of participants to the driving population. Conducting controlled experiments, such as simulator studies, is often expensive and timely, and samples are relatively small precluding generalisation to larger populations. It is important to note, however, that generalisation to a larger population is most often not the aim when conducting controlled experiments. The main aim is rather to say something about causality, by isolating the effect one is interested in and study how behaviour is affected by the experimental variable.

Test track and on-road studies. In order to alleviate the ecological validity problem with artificial study settings in experiments, efforts are made to conduct experiments with some degree of control in more naturalistic or real settings. Such studies can for instance be done in real cars instrumented with equipment to measure various behaviours (e.g., speed, lateral and longitudinal acceleration, eye glance behaviour etc.) in a more realistic driving context. Conducting such a study on a test track involves a more realistic setting with regard to the vehicle in question, but the surroundings – including other vehicles and road users, as well as the traffic situation, road condition etc. – will still be artificial compared to what a driver meets in his or her daily driving. Taking controlled experiments and test track studies a step further on the continuum, we have so called on-road experiments or field experiments. This involves participants driving an equipped car, most often with an observer (experimenter/researcher) present in the car, in a real traffic environment (on the road). However, in order to be able to say something about causality, one still needs to assure some degree of control. This means that, in test track and on-road studies, participants are asked to perform a specific behaviour (talk on a mobile phone, perform a 'cognitive task', drive a specific route, etc.). In turn, behaviour measures can be observed as a consequence of the specific task that is performed. Thus, there are still some artificial elements left in such studies, in that participants are asked to behave in a certain way that they may not have done in their day-to-day driving.

Moreover, participants in test track and on-road studies are being actively observed, i.e., they are observed by an experimenter and/or monitored by means of technical equipment for the short study period. Knowing that one is under observation may have an effect on how participants behave which may be a confounding factor. Such an effect is commonly known as observer effects or reactivity.

Field operational tests (FOT). The main aim of FOT's is to test a system in development; how it is used by drivers and how it affects drivers' behaviour. Vehicles with such a system are equipped with technical devices that measure various driving behaviour and performance indicators (speed, lateral and longitudinal acceleration, eye glance behaviour etc.). Participants drive the test vehicle(s) for a longer period of time (a couple of days to several months), under normal driving conditions. Thus, there are no experimenters/observers present in the vehicles, and drivers are not told to perform specific behaviours (apart from using the sys-

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[2] Ecological validity is part of the external validity, and refers in this case to the degree to which a study setting can be perceived as being artificial or naturalistic/real by the study participants.

tem that is being tested) or drive specific routes. This means that the observation is unobtrusive, the study setting is realistic, and that ecological validity is high.

Depending on the duration of the study, observer effect may be a factor worth considering. In 'short' FOTs participants are more likely to be aware of the fact that they are under observation, and behave accordingly. In FOTs where drivers drive an instrumented vehicle for more than a few days, it is assumed that observer effect is less likely to be a factor (Dingus, Klauer et al. 2006).

Importantly, the main objective of FOTs is to test a specific system and the behaviour of drivers related to that system.

2.1.2 Self-report of driving behaviour

Another method that is widely applied for studying driver behaviour is self-report measures. One of the main advantages of self-report studies is that one can reach a large and more or less representative sample, and generalisation of the results to a broader driver population is possible. Such self-report of driver behaviour is widely used to measure for instance driving exposure (e.g., annual driving distance), driving in the presence of various risk factors ("how often do you talk on a mobile phone while driving?"), as well as various driving behaviours measured by validated question batteries (e.g., DBQ and DAIS (Özkan and Lajunen ; Reason, Manstead et al. 1990). There are, however, several limitations associated with self-report measures of driving behaviour.

The main limitation concerns the fact that self-report is indirect observation of the measures one is interested in. In contrast to experiments and naturalistic driving studies, one relies on the participants' subjective report of their own behaviour. Such self-report is thus subject to various biases, for instance recall biases, social desirability, misunderstanding of questions, inadequate response options, participants 'satisficing' rather than 'optimising' when answering (i.e., they are not motivated to read and answer all questions thoroughly), the gap between intention and behaviour, etc.

2.2 Studying crashes

Crash studies and epidemiological studies. In order to get information about crashes in the driver population and crash risk of various groups, studies based on crash databases are commonly used. Thus, information about the crashes is based on reports by for instance police or insurance companies. Information gained from such databases is of course based on real crashes. Moreover, the sample sizes in such studies are large as such studies aim at giving information about crashes on a population level. However, the information about the crash reflects what is available for the police or the insurance company or other party that records or gathers the data, and the information available may be insufficient. Moreover, observation of variables of interest is indirect (i.e., crashes and related behavioural and characteristic variables are not directly observed), and one cannot rule out errors and biases in the recording of the data. Finally, not all crashes are reported or investigated, precluding a large amount of potentially interesting crash data.

In addition to quantitative studies using crash data, some countries have accident analysis groups that investigate crashes more in depth or qualitatively. In such analyses, efforts are made to gather more information about the context, the driver and other potential contributing factors to the crash. However, information about factors preceding the crashes will always be limited to a certain degree, as there is no direct observation of the potential factors.

Self-report of crashes. The frequency and distribution of crashes and crash risks can also be studied by means of self-report surveys in large representative samples. As with all self-report studies, information gained can be distorted and biased in several ways (recall biases, reluctance to give information about sensitive issues such as crashes, not sufficient information available, etc.).

2.3 Naturalistic driving observation

2.3.1 Studying driver behaviour

In an ideal naturalistic driving study, participants' own cars are equipped with technological devices that record various kinematic measures and video cameras that record the driver's face and behaviour and/or the road and traffic situation. In this way, participants can use their car in the same way as they always do, and their behaviour is recorded and objectively observed in an unobtrusive way while they're driving in their natural driving context. Thus, naturalistic driving involves, as reflected in the name of this method, observing driving behaviour in a naturalistic and realistic context, and the problem of low ecological validity that is associated with more or less controlled experiments, is alleviated.

The downside of naturalistic driving observation is that one does not have the experimental control over potential confounding variables as in a controlled experiment. Thus, it is only possible to observe relationships between variables to some degree, and causal mechanism can only be concluded to a limited extent. That is, a causal relationship can be identified to the degree that one can observe that one factor precedes another – outcome – factor. However, as one does not have control over other potentially influential factors, and considering that no situation will be similar across observations in a naturalistic observation material, one cannot entirely rule out alternative explanations.

As for observer effects, the same goes for naturalistic driving as for field operational tests. Optimally, however, naturalistic driving studies are conducted over a longer period of time, and potential observer effects are assumed to be reduced over time (Dingus, Klauer et al. 2006). However, one cannot preclude observer effects altogether, and in order to prove the validity of naturalistic driving studies, further research should address this issue.

Whereas the main objective of FOTs is to test a specific system or device and behaviour related to that system, naturalistic driving studies are conducted in order to gain information about driving behaviour in general, as well as behaviour and other factors leading to specific events such as accidents and near-accidents.

In naturalistic driving studies one has the advantage of continuous recording of driving behaviour, allowing for unobtrusive objective observation of driving exposure, exposure to various risk factors, violations, errors, aggressive driving etc. It is important to have in mind, though, that a huge amount of data on pure exposure measures will be generated when recording continuously, which place a heavy weight on resources in terms of data gathering, data storage and data reduction and analysis.

2.3.2 Studying crashes

Naturalistic driving observation of crashes. Naturalistic driving observation studies are not only relevant for studying normal behaviour, but also crashes and near-crashes and the behaviour and other relevant factors that contribute to such events. In order to analyse crashes/near-crashes and related behaviour and contributing factors, one important requirement is that there are sufficient kilometres driven in the study sample for crashes/near-crashes to actually happen. Thus, to be able to say something about crashes and near-accidents, a naturalistic driving study should have a large sample of drivers participating for a longer period of time.

Also, although crashes happen far too often on an aggregated level, they are relatively rare events. In the so-called 100-car naturalistic survey[3], for instance, approximately 2,000,000 vehicle miles were recorded, and 82 crashes were identified of which data were eligible for 69 (Dingus, Klauer et al. 2006). Thus, statistical analyses using crash data only is limited at best. However, results from the 100-car study showed that measuring less severe conflict surrogates such as near-crashes can provide reasonable estimates of crash risk if a larger-scale study is conducted. Importantly though, a lesson learned from the same study is that pure quantitative identification of near-crashes needs to be validated by qualitative investigation of video data (Dingus, Klauer et al. 2006). Another option is to include so called ‘incident boxes’ that a driver can push if she or he judges the situation to be a conflict situation. It is important to have in mind, though, that even though near-crashes and actual crashes are similar with regard to certain events and kinematic patterns, these two types of events are not the same and that, in the end, actual crashes are of main interest.

One advantage of naturalistic driving studies compared to crash data obtained through police reports or insurance companies, is that one gets information about all types of crashes – also less severe crashes that most often are not reported to the police. In the 100-car naturalistic data, for instance, 82 crashes were identified, but only 15 of these were reported to the police, indicating that crash involvement is far higher than indicated by police-reported crashes (Dingus, Klauer et al. 2006).

The main advantage with analysing crashes/near-crashes by means of naturalistic driving observation is of course the direct observation of driver behaviours, and depending on the technical equipment, environmental factors as well as road and traffic variables, preceding the event in question. Thus, assuming one has a large sample, naturalistic driving observation studies allow for investigating crashes both quantitatively and qualitatively.

2.3.3 Naturalistic driving observation: Strengths and weaknesses

To sum up, naturalistic driving observation alleviates a range of the problems associated with the mentioned traditional methodological approaches. Roughly, the problems with the traditional ways of studying traffic and transport behaviour and crashes are 1) that all studies based on self-report and crash data bases (and not having experimental control) rely on indirect observations of the measures we are interested in, and subsequently are subject to various biases and errors (whether

[3] The 100-car study is described in more detail in section 5.1.1.

it is crashes, incidents or behaviour), and 2) that in studies in which one has direct observations, i.e., experiments, the external validity is low and generalizations hard to make.

By using naturalistic observation, one is able to directly observe actual driving (like in simulation experiments) while avoiding the artificial experimental setting. However, as discussed in the previous paragraphs, there is a trade-off between strengths and weaknesses:

Methodological strengths:

- Direct observation of behaviour and accidents/near-accidents/critical incidents
- High ecological validity, i.e., naturalistic and realistic context
- Unobtrusive, strengthening ecological validity, limiting reactivity/observer effect (that participants change behaviour merely because they are observed)
- Long duration, limiting reactivity
- Objective observations, not subject to recall biases, whereas social desirability and experimenter effects are minimised
- Generalisation of results, when large samples
- In-depth information about factors contributing to accidents

Methodological weaknesses:

- Low internal validity with respect to causal explanation, low control over external variables
- Potential for biased samples
- Potential for observer effect
- Resource demanding in terms of sample, duration, data gathering, data storage, data analysis

A last point concerns the building up of a large data base that can be used for investigating various research questions. More specifically, conducting naturalistic driving observation studies allows for the build up of a large database that includes measures of an enormous amount of variables that are relevant for investigating various traffic safety issues. Obviously, for a specific project in time, only a subset of variables will be relevant for addressing the research objectives in question. However, such a data base is invaluable in terms of potential use for research projects that can be specified after the data gathering.

3 Guiding questions

The aim of the remaining of this document is to review relevant literature on traffic behaviour using naturalistic driving observation. The literature review is to be used as a basis for recommending important research questions that can be answered using naturalistic observation as a method within the field of traffic behaviour. Traffic safety (including safety of vulnerable road users) is the main focus in the project, but other aspects of traffic behaviour, such as environmental friendly driving (i.e., eco-driving), and traffic flow/management issues are also addressed.

The following questions serve as guide-lines for the present review:

- What transport safety issues have been studied using naturalistic driving observation?
- Is naturalistic driving observation suitable for studying various driving behaviour measures?
- Is naturalistic driving observation suitable for studying environmentally friendly and sustainable driving (i.e., eco-driving)?
- Is naturalistic driving observation suitable for studying behaviour of vulnerable road users?
- What are the strengths of naturalistic driving observation within the various fields/areas?
- What are the weaknesses and limitations of naturalistic driving observation within the various fields/areas?
- Are there areas within the field of traffic behaviour that have not been studied using naturalistic observation, and that would gain from using this method?

4 Literature selection criteria

In the present literature review, various types of documentation of naturalistic driving observation studies are presented. As naturalistic driving observation is relatively new as a method, and as this and related methods are not only of academic interest, the review is not limited to scientific peer reviewed papers only. Table 4.1 shows the types of documents included in the literature review, and the division of labour between the PROLOGUE partners concerning the review of the literature.

Table 4.1 Division of labour

Document types	Responsible institution	Appendix
Scientific peer reviewed papers	TØI	Appendix I
Published reports	TØI	Appendix I
Reports/projects/studies, unpublished material from European organisations	CERT-HIT	Appendix II
Reports/projects/studies, unpublished material from organisations outside Europe	TTI	Appendix III

Literature searches were conducted using various means. First, for peer reviewed papers, searches were made in scientific databases (e.g., ISI Web of Knowledge, Science Direct, and National Transportation Library (TRB), using the following search words in different combinations: 'naturalistic observation'/'naturalistic driving'/'field operational test' and 'driving'/'driving behaviour'/'traffic safety'/'traffic flow'/'eco-driving'. Reviews of the abstracts were conducted, and relevant articles included for the final review.

In addition, random searches were made on internet (http://scholar.google.com).

Finally, the 'snowballing' method was used, i.e., references in articles and reports that were found interesting by the researchers were investigated and included if relevant.

As for reports/projects/studies, unpublished material from Europe and outside Europe, e-mails were sent to contact persons, research fellows, and various organisations, asking for information on finished and ongoing naturalistic driving studies.

Inclusion criteria for what kind of studies that would be suitable for the present study were developed (see Table 4.2). These guidelines were roughly followed. It should be noted though, that the inclusion criteria were supplemented with subjective judgments and that some included studies/projects may not adhere strictly to the proposed guidelines.

Table 4.2 Guidelines for including studies in literature review

Inclusion criteria	Specification
In-vehicle recording of driver actions	Applications using only vehicle parameters (speed, acceleration, lateral position, etc.) and not including driver or road scene video, are to be included only if data are related to characteristics of driver or traffic environment
Driving in traffic	Do not include studies of driving on closed tracks
Normal driving, i.e., no experimenter or professional observer in vehicle	Exception: Studies using driver observation during driver training with an instructor are relevant.
Continuous data acquisition	Applications using « accident/event data recorders » (ADR/EDR) and saving data for only a few seconds before and after an accident/incident are less interesting for our purpose.
Both experimental and private instrumented vehicles	Studies using experimental cars should only be included as long as the remaining criteria listed here are satisfied
Regular FOTs should not be included	FOTs should be included if purpose is to study effects of equipment on *driver actions*, and not assessment of the equipment per se, such as technical aspects, user acceptance, etc.
Other	Other studies may be included if you consider them especially relevant or interesting examples of naturalistic driving, which may have implications for the choice of research questions and applications in future ND studies

5 Review of the literature

In order to give the reader an idea about how a typical naturalistic driving study is designed and conducted, a short overview of three typical naturalistic driving studies is presented in section 5.1. In sections 5.2 to 5.12 a discussion of the naturalistic driving literature in various fields is presented. Abstracts of the studies discussed can be found in Appendices I to III.

5.1 Three large naturalistic driving studies

5.1.1 100-Car Naturalistic Driving Study

One hundred drivers who commuted on a regular basis in the Northern Virigina/Washington D.C metropolitan area were recruited to the study. 78 drivers drove their own car, whereas 22 drivers used leased cars. All cars were instrumented, and data were collected over an 18-month period. Drivers using their own car received $125 per month and a bonus at the end, whereas drivers using a leased car received free use of the car and a bonus at the end.

All vehicles were instrumented with a package engineered by Virginia Tech Transportation Institution (VTTI). The instrumentation included the following: a vehicle network box that interacted with the vehicle network, an accelerometer box obtaining longitudinal and lateral kinematic information, headway detection system providing information on leading or following vehicles, side obstacle detection to detect lateral conflicts, incident box, video-based lane-tracking system and video to validate any sensor based findings. The video-equipment consisted of 5 cameras monitoring the driver's face and driver side of the vehicle, the forward view, the rear view, the passenger side, and a view of the driver's hands and surrounding areas.

The data set included approximately 2,000,000 vehicle miles, 43,000 hours of data gathered over a period of 12-13 months for each vehicle.

This research effort was initiated to provide an unprecedented level of detail concerning driver performance, behaviour, environment, driving context and other factors that were associated with critical incidents, near crashes and crashes. A primary goal was to provide vital exposure and pre-crash data necessary for understanding causes of crashes, supporting the development and refinement of crash avoidance countermeasures, and estimating the potential of these countermeasures to reduce crashes and their consequences.

Operational definition for events in the 100-Car Naturalistic Driving Study:

- Crash: Any contact with an object, moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated. Includes other vehicles, roadside barriers, objects on or off the roadway, pedestrians, cyclists, animals, etc.
- Near-Crash: Any circumstance that requires a rapid, evasive manoeuvre by the subject vehicle, or any other vehicle, pedestrian, cyclist or

animal to avoid a crash. A rapid, evasive manoeuvre is defined as a steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities.

- Crash-relevant conflict: Any circumstance that requires a crash-avoidance response on part of the subject vehicle, any other vehicle, pedestrian, cyclist or animal that is less severe than a rapid evasive manoeuvre, but greater in severity than a 'normal manoeuvre' to avoid a crash. A crash avoidance response can include braking, steering, accelerating, or any combination of control inputs.
- Proximity Conflict: Any circumstance in extraordinarily close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object where, due to apparent unawareness on part of the driver, pedestrians, cyclists, or animal there is no avoidance manoeuvre or response. Extraordinarily close proximity is defined as a clear case where the absence of an avoidance manoeuvre or response is inappropriate for the driving circumstances.

Self-report measures used in the 100-Car Naturalistic Driving Study:

In addition to objective driving observations, self-report measures were obtained by administering various surveys and test-batteries. The surveys and test batteries used were:

- Driver demographic information (general information on driver age, gender etc.)
- Driving history (general information on recent traffic violations and recent collisions)
- Health assessment questionnaire (list of illnesses/medical conditions/or any prescriptions that may affect driving performance)
- Dula Dangerous Driving Index (one score that describes driver's tendencies towards aggressive driving)
- Sleep hygiene (list of questions that provide information about driver's general sleep habits/substance use/sleep disorders)
- Driver Stress Inventory (one score that describes the perceived stress levels drivers experience during their daily commutes)
- Life Stress Inventory (one score that describes drivers stress levels based upon the occurrence of major life events)
- Useful Field-of-View (assessment of driver's central vision and processing speed, divided and selective attention)
- Waypoint (assessment of the speed of information processing and vigilance)
- NEO-FFI (personality test)

- General debrief questionnaire (list of questions ranging from seatbelt use, driving under the influence, and administration of experiments).

(Dingus, Klauer et al. 2006).

5.1.2 SHRP2

A large-scale naturalistic driving study will be included as a part of the US Strategic Highway Research Program 2 (SHRP2). The in-vehicle driving behavior study will be conducted with volunteers driving instrumented vehicles for everyday use. An instrumentation package will be developed for installation on many vehicle models. The drivers will use their own vehicles during the study period. The driver and vehicle pool will change at least once a year through the reinstallation of the instrumentation package in a new driver's vehicle. The data collection package will accommodate requirements for a variety of analyses of lane departure, intersection crashes, and other questions. The study will be conducted in several geographic areas to accommodate variations in weather, geographical features, and rural, suburban, and urban land use. Data will be archived for analysis as part of the data processing and will be made available to qualified researchers. Another critical need in the in-vehicle study of driving behaviour is for detailed roadway data, with greater coverage of the roads used by the volunteer drivers. These data will support the association of driver behaviour with roadway characteristics such as grade, curvature, and posted speed limits.

The field studies envisioned under SHRP2 will produce large data sets. Although data collection technology has advanced rapidly in the past few years, analytic methods have not kept pace. The field data collection projects therefore are supported by a series of projects to develop analytic methods. Key aspects of the analyses include the application of crash surrogate approaches, such as traffic conflicts, critical incidents, near-collisions, and other surrogate measures; development of exposure-based collision risk measures; and the formulation of analytic methods to quantify the relationship of human factors, driver behaviour, and vehicle, roadway, and environmental factors to collision risk.

(Campbell and Mason, 2008)

5.1.3 Heavy vehicle study

The main objective of this study was to investigate driver distraction among commercial vehicle operations using naturalistic driving data (Olson, Hanowski et al. 2009). Data from two previous naturalistic studies were combined, and the two data sets represented 203 commercial vehicle drivers, and approximately 5 million km of data including kinematics and video data. The dynamic performance measures included longitudinal and lateral acceleration and braking, and the video included view of the driver's face, as well as forward, backward left, and backward right road views.

Trained data analysts identified so-called safety critical incidents defined as crash, near-crash, and crash-relevant conflicts. This was done by running the data through a software programme in which incidents were flagged based on certain thresholds: longitudinal acceleration (hard braking), time-to-collision, swerve, critical incident box, and analyst identified events. For each safety-critical incident, the analyst defined type of conflict, potential distractions, driver behaviour, and road and environmental conditions.

4452 safety-critical events were identified in the dataset, including 21 crashes. In order to be able to estimate odds ratios, baseline events were also gathered, i.e., uneventful, routine driving.

(Olson, Hanowski et al. 2009)

5.2 Driver distraction and inattention

5.2.1 Traditional methods for studying driver distraction and inattention

Driver distraction has been found to be a contributing factor in 8 to 25 percent of road accidents (Stutts, Reinfurt et al. 2001; McEvoy, Stevenson et al. 2007). With the proliferation of potential in-vehicle distraction factors such as mobile phones and electronic route guidance systems, as well as various electronic entertainment systems, research on driver distraction and related driving behaviour has increased within the field of traffic safety in the last twenty years.

When it comes to research on driver distraction factors in general, roughly one can say that three different types of traditional studies can be identified: 1) studies investigating distraction factors and their potential *effects on driving behaviour*, 2) crash studies describing the *prevalence* of various distraction factors in *crashes*, and 3) *crash risk studies* investigating the risk associated with various distractions. Studies belonging to the first category are typically experiments conducted in a simulator or on a test track in order to have high control over potential confounding variables and be able to isolate the distraction effect in question (Collet, Clarion et al. in press; Young, Mahfoud et al., 2009; Jamson, Westerman et al. 2004; Tsimhoni, Smith et al. 2004, Horberry, Anderson et al. 2006; Chisholm, Caird, et al. 2008; Young, Mahroud et al. 2008).

The second type of studies is often based on large crash databases. Results show that one or more distractions contribute to between 8 and 25 percent of crashes (Stutts, Reinfurt et al. 2001; Gordon 2009). Whereas such studies are important with regard to knowing the extent of contribution of various distractions to accidents, it is not possible to say anything about the relative risk associated with the distraction in question. This is due to the fact that in pure crash studies, one lacks information about the exposure to the risk factor, i.e., how often the drivers are exposed to the distraction in question.

Traditionally, research on distraction related accident risk has been sparse relative to the other two types of studies. Most accident risk studies on distractions have focused on mobile phone use, and the results show an increased accident risk related to such use (Redelmeier and Tibshirani 1997; Sagberg 2001; Laberge-Nadeau, Maag et al. 2003; McEvoy, Stevenson et al. 2007). As for other distractions than mobile phone use, research has found increased accident risk associated with having passengers in the car – especially among novice drivers (McEvoy, Stevenson et al. 2007; McEvoy and Stevenson 2009). In addition, Lam (2002) found in-vehicle distractions to be significantly associated with accident risk whereas outside vehicle (external) distractions were not.

5.2.2 Naturalistic driving studies on driver distraction and inattention

The potential of naturalistic driving studies within the field of driving distraction and inattention is multifaceted, and previous naturalistic driving studies have investigated all three issues described above. First, in addition to strictly controlled experiments conducted in simulators or driving tracks in order to study the *effect of various distractions on behaviour*, naturalistic driving studies have gained interest, as these allow for investigation of driving behaviour and attention while avoiding the artificial experimental setting associated with simulator studies (Barr, Yang et al. 2003; Stutts, Feaganes et al. 2005; Klauer, Dingus et al. 2006; Klauer, Sudweeks et al. 2006; Olson, Hanowski et al. 2009). Almost by definition, naturalistic driving studies address the effect on driving behaviour of the distraction factors studied; the presence of the distraction in question is investigated in relation to various behavioural measures. The behaviour can be a) the directly observed behaviour of the driver (e.g., eye glance pattern, number and position of hands on the steering wheel), and b) the observed driving behaviour measured as position of the car, longitudinal and lateral accelerations, speed, following headway etc. The advantage of naturalistic studies over different types of experiments is that the associations between distractions and behaviour are observed in a naturalistic and real context, and the study situation is not artificial. However, compared to experiments, one lacks the strict control over the situation and potential confounding variables, and causal explanations can only be concluded to a limited degree. Results from naturalistic observation studies indicate that distractions are associated with increases in eye glance durations to the side mirrors and inside the vehicle (Barr, Yang et al. 2003), higher levels of no hands at the steering wheel, and higher rates of adverse vehicle events (e.g. lane wanderings and sudden brakings) (Stutts, Feaganes et al. 2005).

It is not only the effect of driver distraction (i.e., distraction as independent variable) that may be of interest, but also driver distraction as outcome or dependent variable. In a study by Sayer et al. (2005), the main objective was to investigate whether driving with an in-vehicle support safety system (adaptive cruise control (ACC) and forward collision warning (FCW)) increased drivers' risky behaviour, i.e., if drivers would compensate for the increased safety of such a support system by engaging in more distractive (risky) activities. The results from this study indicated that drivers were no more likely to engage in secondary behaviours when driving with ACC and FCW in comparison to manual control.

Second, naturalistic driving observation is also suitable for investigating the *prevalence of various distraction factors in crashes*. In particular, in studies with large samples conducted over a longer period of time, there will be a number of accidents, near-accidents, and critical incidents. However, as the number of accidents probably will be limited to some degree, near-accidents and critical incidents can be used as proxies for real accidents. Typically, in a naturalistic study, events (accidents, near-accidents, and critical incidents) are identified by means of quantitative, kinematic triggers that can be analysed in detail. A time slot of what happened before, during and after such events are subsequently analysed in detail, and the presence of distraction factors can be identified. Results from Hanowski et al. (2005) showed that distraction was designated as the primary cause for 7 percent of 2737 critical incidents (no crashes were recorded in this study). No gender or age effect was observed, but two drivers accounted for 24 percent of the distraction related incidents.

In naturalistic driving studies, the prevalence of distraction factors in crashes is often just a part of a broader analysis of relative risks associated with the various distraction factors. The main obstacle for estimating accident risk and relative risks in non-naturalistic studies is probably that it is difficult getting good exposure data on the various distraction factors. That is, one does not have information about how often drivers are exposed to/engage in the various distractions in their normal driving, i.e., not related to accidents. In naturalistic driving studies, however, one has the potential to record driving behaviour continuously, and thus estimate relative risks. Pure estimates of exposure was for instance studied by Stutts et al. (2005) who found that of the total time the vehicles were moving, conversing was observed in 15.3 percent, preparing to eat/drink was observed in 3.16 per cent, followed by smoking (1.55 percent), eating and drinking (1.45 percent), and using a mobile phone (1.3 percent of the time).

Using exposure data on distractions and prevalence of distractions in accidents and near-accidents, some naturalistic studies have estimated relative risks (odds ratios) and corresponding population attributable risks. Results from the 100-car naturalistic study indicate that complex secondary tasks increase risk (for accidents and near-accidents) by three times, whereas moderate secondary tasks increase risk by two times. Moreover, analyses of eye-glance behaviours indicate that having the eyes off the road for more than 2 seconds significantly increased accident/near-accident risk (Klauer, Dingus et al. 2006). The importance of vision and the detrimental effects of having the eyes off the forward road for more than 2 seconds, is also documented in a study on distraction in commercial driving (Olson, Hanowski et al. 2009); the results clearly showed that the tasks associated with highest risk were those in which the drivers' eyes were drawn away from the forward road. More spesifically, the highest risks were associated with *texting* on cell phone, and other complex tasks such as cleaning the side mirror, and interact with/look at dispatching devices (Olson, Hanowski et al. 2009).

Whereas relative risks say something about how risky each distraction factor is, population attributable risks consider also the frequency or prevalence of the distraction factor in question. The point is that even though a distraction factor has a high relative risk, it may be so rare that eliminating the distracter would not reduce accidents. In Olson et al. (2009) they found that the distracters with highest population attributable risk among commercial drivers were 'interact with/look at dispatching device', 'dial mobile phone', 'read book/newspaper/paperwork' and 'look at map'.

Summing up the above paragraphs, naturalistic observation is particularly promising in the field of studying driver distraction as it is possible to gain data on the frequency of distractive activities under normal driving, allowing for estimation of relative risks (odds ratios) and population attributable risk.

The importance of conducting naturalistic driving studies can also be illustrated by comparing results found in simulator studies with results from naturalistic studies. The case of mobile phone use and differentiated effects of hand-held and hands-free phones is discussed by Olson et al. (2009). For instance, while simulator studies have found detrimental effects of talking or listening on hand-held and hands-free phones while driving, naturalistic driving studies have failed to find such effects. Actually, as for talking or listening to a hands-free phone, Olson et al. (2009) found a significant protective effect among commercial vehicle drivers. The notion that there is cognitive distraction at work when talking or listening to a phone while driving, is challenged by naturalistic driving studies. One explanation for these contradictory findings is that the true nature of drivers' behaviour is not revealed in controlled study settings and consequently that such studies cannot account for the risk perception and consequent behavioural adaptation of the driver. For instance, a driver may compensate for the fact that he or she is talking on a phone by being more alert and drive more steadily. In this respect, naturalistic studies may provide a better picture of the drivers' behaviour than e.g., simulator studies.

5.3 Drowsiness and fatigue

Driver drowsiness[4] is acknowledged as a significant contributing factor to road crashes, and although there are discrepancies in reported estimates in the literature, sleepy driving crashes have been found to contribute to at least 1 to 6 percent of all crashes, and 3 to 15 percent of fatal crashes (Sagberg 2008). Due to underreporting, the actual incidence of sleep-related crashes is probably considerably higher than most estimates in the research literature.

In order to understand driver drowsiness and its effects on driving behaviour and accidents risk, there are various issues that need to be addressed in research, e.g., how to measure drowsiness, occurrence of driver drowsiness, the causes of drowsiness, how to model drowsiness and accident risk, as well as developing countermeasures for driver drowsiness and accidents. In particular, we need to be able to identify driver drowsiness so that (a) reliable countermeasures can be developed (based on objective measures of driver drowsiness rather than less reliable subjective measures of driver drowsi-

[4] The terms drowsiness, sleepiness, and fatigue are used interchangeably in the literature. Although these terms refer to distinct states, all refer to the driver's level of wakefulness and whether the driver has shown signs of falling asleep at the wheel.

ness); and (b) it can be more easily classified as a variable in epidemiological and other research studies.

Driver drowsiness is traditionally typically studied in epidemiological studies or simulator studies, depending on the research questions addressed. In epidemiological studies and in-depth accident analyses, drowsiness can only be inferred as a contributing factor when other alternative causes have been eliminated, and such identification is both timely and error-prone (Liu, Hosking et al. in press). In simulator studies one has the possibility to manipulate drowsiness to some degree, which would be unethical in more naturalistic studies. However, the issue of an artificial study setting is a problem in simulator studies, and with regard to drowsiness studies it has been suggested that the simulator setting may be drowsiness inducing in itself (Anund, Kecklund et al. 2009).

Drowsiness can be measured in various ways. *Physiological measures* of drowsiness can be recording of EEG (electrical brain ways), EOG (eye movements), camera based eye movement recordings (e.g., PERCLOS), and recording of behavioural signs of sleepiness (e.g., body movements, gestures, facial tone and head movements).

PERCLOS (Percentage of eyelids closure) was developed in simulator studies and has later been applied in naturalistic driving studies (Tijerina, Gleckler et al. 1999), but researchers have questioned its validity when (a) drivers are aware of their fatigue and trying to keep their eyes open; and (b) it is affected by road lighting etc. (Liu, Hosking et al.). These points suggest that PERCLOS may not be valid surrogates for driver drowsiness in real situations. These limitations are not addressed by Hanowski's study applying PERCLOS in real world settings (Hanowski, Wierwille et al. 2003).

EEG is not practical as a physiological measure of drowsiness in naturalistic studies. It is an invasive method not suited to naturalistic experiments carried out over the course of weeks, and the output is contaminated by artifacts.

Moreover, drowsiness can be measured by *driving parameters* associated with performance impairments during sleepy driving, such as increased variability of lateral position. Simulator studies show that the number of lane departures increases as participants drive for longer durations. Simulator to real-world comparisons have been carried out up to two hours, showing that lane departures do not increase in real-world driving (Liu, Hosking et al. in press). Further research comparing simulator studies with real world studies on lane departure and drowsiness is needed in order to gain further insights.

Finally, *subjective ratings of sleepiness*, such as KSS (Karolinska Sleepiness scale) or the Stanford Sleepiness Scale have also been used. Concerning the measurement of drowsiness, either the Stanford Sleepiness scale or the KSS can be used in naturalistic situations (Liu, Hosking et al.). Of these the KSS appears to be the most commonly used. It is correlated in simulators to lane departures occurring on average eleven minutes after reports of high levels of sleepiness. One interesting question could be what happens in real-world driving when such high levels of sleepiness are reported according to the KSS? However, introducing a self-report questionnaire that asks about a specific trip (such as KSS) will make the driver aware of the purpose of the study, which again may affect the level of alertness and drowsiness. Thus, introducing KSS may distort the true naturalistic purpose of the study.

Although lane deviation appears to be suggested by simulator studies as the measure of vehicle dynamics that is most closely associated with ratings on the KSS, there is large variation between drivers, some drivers having minimal lane deviation when KSS ratings are high (Liu, Hosking et al. in press). This has relevance for systems aiming to predict driver drowsiness from vehicle dynamics. The systems may turn out not to be valid for a certain pool of drivers.

Driver drowsiness is particularly interesting with regard to commercial drivers and in particular long haul drivers as they drive for long durations and at night. For instance Dingus et al. (2006) investigated critical incidents associated with fatigue issues in a naturalistic study among long haul truckers. They found clear support for fatigue as an issue in long-haul safety. Also, the results showed that single drivers and team drivers differed with regard to number of critical incidents, as well as when they were drowsy; team drivers were rated as 'very drowsy' in critical incidents at night, single drivers were rated as 'very drowsy' mostly in the afternoon, but also in the morning, evening and night. This may imply that organisational factors are important, and should be accounted for in studies on drowsiness and fatigue among commercial drivers.

The issue of fatigue among long-haul truckers has also been addressed in studies by Hanowski et al. (Hanowski, Hickman et al. 2007; Hanowski, Hickman et al. 2009). In particular, these studies have investigated fatigue related to revision of HOS-regulations (hours of service) in the US. The revision of the HOS-regulations involved a) a 2 hour extension of off-duty time from 8 to 10 hours to give more time for restorative sleep, and b) an extension of maximum daily driving time from 10 to 11 hours. Thus, these studies do not investigate fatigue linked incidents as such, but rather the amount of sleep the drivers get and its relation to involvement in critical incidents. The results showed that there was no difference in occurrence of critical incidences between the tenth and eleventh hour of driving, indicating that the extension of driving time by the revised HOS has not been detrimental to safety for these drivers (Hanowski, Hickman et al. 2007; Hanowski, Hickman et al. 2009).

Summing up, naturalistic driving studies have the potential for gaining more reliable and valid measures of driving drowsiness, perhaps in particular with regard to lane deviations and eye-closure. However, naturalistic driving precludes other measures such as EEG that can be used in simulator studies. Also, using self-report of driver drowsiness in naturalistic studies should be questioned, as such self-report will raise the driver participant's awareness which in itself could affect the respondent to be more alert – and less drowsy.

Moreover, naturalistic studies of driver drowsiness can give more valid information about the circumstances and times of day when driver drowsiness is most frequent.

Taking a more applied perspective, naturalistic driving studies are of value for investigating organisational approaches to fatigue management in commercial vehicle companies.

5.4 In-vehicle systems

A significant objective within safety research is to develop and evaluate in-vehicle systems that may support drivers in their daily driving. Such systems may support the driver in that driving or other tasks that need to be attended to while driving (e.g., finding one's way) become easier and/or safer. One important step in the development and evaluation of such in-vehicle support and safety systems is to test the system in question in a real driving context. By testing the systems in real driving one can study how drivers use the system in question, how often it is used, if the system works as intended (i.e., that forward collision warning actually warn the driver at the appropriate time), if there are any unintended side effects, how it affects the drivers' behaviour, and if accident risk is reduced. The standard type of study in this regard is field operational test (FOT). One definition of FOTs is given in TELEFOT (Field Operational Tests of Aftermarket and Nomadic Devices in Vehicles): "…a test run under normal operating conditions in the environment typically encountered by the subjects and the equipment being tested" (Karlsson et al. 2009). Thus, in a FOT the main objective is to test a specific system, be it in-vehicle or nomadic brought into the vehicle, by use of more or less naturalistic methods. In particular, in the SemiFOT project it is distinguished between 'naturalistic FOTs' in which an unobtrusive observation of drivers driving their own vehicles on a daily basis and 'other FOTs' typically run on test-tracks, with one or two equipped cars, and a limited amount of participants etc. A wide range of FOTs have been and are presently going on in Europe: Tele-FOT, SemiFOT, Test Site Sweden, EuroFOT, AOS, SIM^{TD}, FESTA etc.

Naturalistic driving studies may also address the question of in-vehicle support systems and nomadic devices, but then the main objective is often not to test the system per se. Rather, the main objective in such naturalistic driving studies is to investigate the behaviour of the driver. However, there is no clear cut difference between naturalistic FOTs and 'pure' naturalistic driving studies. We have precluded a thorough review of all FOTs in the present project, and prioritised studies with a more naturalistic observation perspective.

One interesting question with regard to the effect of in-vehicle support systems is if such systems have any unintended effects on behaviour. As touched upon in the section on distraction and inattention, this has been studied by Sayer et al. (2005). The proposed mechanism, although not explicitly discussed in the paper, is that of risk compensation. That is, the perceived (and intended) increase of safety that comes with an in-vehicle safety system is compensated for by driving more risky, for instance driving faster, more aggressively, or engage in more secondary (distractive) behaviours. A traditional assumption is that the intervention or system in question has to be either intrusive or conspicuous in order to be compensated for. However, some researchers also claim that there is a distinction between *injury reducing* and *accident reducing* interventions, and that normally only the latter are compensated (Graham 1982; Lund and O'Neill 1986; OECD 1990; Bjørnskau 1995; Sagberg, Fosser et al. 1997). The main objective in the study by Sayer et al. (2005) was to investigate if there was an increase in secondary behaviour when driving with the accident reducing systems Forward Collision Warning (FCW) and Adaptive Cruise Control (ACC). The results indicated that there was no increase in distractive secondary behaviours, except from talking with a passenger, which was interpreted as drivers *explaining* the systems to the passenger in question. However, such systems may be compensated for by other risk indicative behaviours than engaging in distractive activities, such as for instance driving faster. Moreover, in the study by Sayer et al. (2005), FCW and ACC are tested simultaneously and it is not possible to distinguish between the two. Thus, further research should address the question of risk compensation of various injury and accident reducing systems in naturalistic driving studies.

In an ongoing project, INTERACTION, the main objective is to use various methods to study and understand driver interaction with mature in-vehicle technologies in the market. Naturalistic driving observation is one of the methods that will be used to identify drivers' patterns of use of in-vehicle technology in everyday life, and the implication of such use for safety.

Naturalistic driving observation has also been used to develop a method for evaluating the performance of collision avoidance systems (CAS) based on speed and acceleration data for the subject vehicle and, separation between two vehicles (McLaughlin, Hankey et al. 2008). In this study, different algorithms were developed in order to define the latest point in time where a deceleration would be necessary in order to avoid a collision. The naturalistic driving data enabled identification of the 'observed response point', i.e., the point in time when the driver initiated an avoidance response. Various algorithms were tested, and the results indicated that the frequency of false alerts appeared to be unacceptably high, warranting further developing of CAS and research on the performance of this system. Moreover, the study demonstrates the potential and usefulness of naturalistic studies investigating in-vehicle systems.

Thus, naturalistic driving studies allow for investigating drivers' behaviours associated with various in-vehicle systems, like for instance risk compensation and behavioural adaptations, as well as testing and evaluating various systems by investigating the behaviour of drivers.

5.5 Lane-change behaviour

Knowledge about lane-change behaviour is important both with regard to safety issues and traffic flow issues. It has been estimated that lane change crashes account for approximately 4 to 10 percent of all crashes (see Lee et al. 2004), and knowledge about lane-changing behaviour can for instance be used in the designing of technology such as CAS systems to minimise both frequency and severity of lane-change accidents.

Lane-change behaviour has been studied by use of naturalistic data and thus allowing for investigation of such behaviour in real-world settings. In a study by Lee et al. (2004), various research objectives were addressed, among them investigation of eye-glance patterns related to lane-changing behaviour, how often various types of lane changes occur, lane changes in different environments, and lane changes for various vehicle types. The results showed that left lane changes had a mean duration of 11 seconds. Slow lead vehicle lane change was the largest category with a mean duration of 13 seconds, supporting the notion that lane changes to a high degree are caused by a slower lead vehicle. All in all, the lane changes were low in both severity and urgency. However, an in-depth analysis of higher severity lane changes were conducted, showing that there was a weak tendency indicating higher speed at lane change initiation was associated with higher severity and urgency. Eye-glance analyses showed that there was at least one glance to the forward view during the 3 seconds prior to a lane change. However, turn signal were used in only 44 percent of the time, with more signal use for left lane changes than right lane changes (Lee, Olsen et al. 2004). This study clearly shows the potential for using naturalistic driving data to investigate lane change behaviour. However, the study be Lee et al. (2004) was conducted in a rural area, and the traffic density was lower than what is expected in urban areas. Thus forward and rearward envelopes will probably be smaller in an urban setting. Lane change behaviours should be investigated further in different traffic environments to get a fuller picture of this behaviour. The knowledge gained is important for instance with regard to developing lane change warning systems. In addition, naturalistic driving studies with large samples could generate knowledge on accident risk associated with various types of lane changes.

Knowledge about lane change behaviour is not only important with regard to safe driving behaviour and accident risk, but also with regard to traffic management and traffic flow where such knowledge is used as input in lane change models. Toledo and Zohar (2007) point to the fact that previous models of lane changing behaviour neglect the detailed modelling of the lane-changing action itself, and model it as an instantaneous event. Naturalistic driving studies have the potential to investigate durations of lane change behaviour. In the study by Toledo and Zohar (2007), a variant of naturalistic observation study was conducted. However, this was a site based naturalistic study, not an in-vehicle naturalistic study. The results showed that the mean duration of lane changes was far lower in Toledo and Zohar's study than in the study by Lee et al. (2004), with mean duration of all lane changes of 4.6 seconds (compared to 9.07 in Lee et al. (2004)). In both studies, lane changes to the left had a longer mean duration than to the right, which is explained by Toledo and Zohar (2007) as a risk aversion effect – changing lanes to the left most often involves changing to a faster lane, which is more risky, and consequently drivers behave more cautious and take longer time.

Toledo and Zohar (2007) also investigated differences between heavy vehicles and light vehicles with respect to lane changes. They found that mean duration of lane changes were shorter for heavy vehicles than light vehicles. However, for both types of car, lane-change durations were longer when the maneuver was riskier or when the task was complicated by other vehicles. Lane change durations in general were found to be affected by traffic conditions, direction of the change and other vehicles around the subject vehicle.

These studies show that naturalistic driving observation – both in-vehicle and site based studies – allow for detailed investigation of lane change behaviours; information that can be applied in both modelling of traffic flow and when designing collision warning systems.

5.6 Heavy vehicle – light vehicle interaction

Naturalistic driving studies may also be applied for investigating behaviour and risk of drivers of different vehicles including ‘regular’ cars, trucks, and motorcycles (see for instance *http://www.2besafe.eu/* for information about naturalistic observation of powered two-wheelers). One potential research issue when studying behaviour of drivers of different vehicles is the interaction between drivers of the different vehicle types. In the 100-car study, interaction between light vehicles and heavy vehicles was investigated from the perspective of the light vehicle drivers (i.e., they had in-vehicle data from the light vehicle drivers) (Hanowski, Olson et al. 2006), whereas Hanowski et al. (2007) in another study used naturalistic driving data from the heavy vehicle drivers' perspectives.

Results from both studies indicate that light-vehicle drivers were at fault in a majority of the incidents in which culpability could be identified; 78 percent of the incidents in the heavy-vehicle perspective study were initiated by light-vehicle drivers, whereas 64 percent of the incidents in the 100-car study incidents were found to have been the fault of the light vehicle. Moreover, the results suggest that the most important contributing factors differ between light vehicle at-fault drivers and heavy vehicle at-fault drivers. More specifically, Hanowski et al. (2007) found that the primary contributing factor when light vehicle drivers were at fault was ‘aggressive driving’, whereas the primary contributing factor for heavy vehicle initiated incidents was ‘poor driving skills’. ‘Aggressive driving’ was also a contributing factor for light vehicle at-fault incidents in the 100-car study, however to a lesser degree than what was found by Hanowski et al. (2007). This discrepancy may indicate that there are difficulties with regard to interpreting the behaviour of drivers *not* driving equipped, subject vehicles.

Moreover, results from the 100-car study indicate that the most frequent primary manoeuvres of light vehicle drivers at-fault were connected to difficulties of decelerating or stopping, whereas the most frequent primary manoeuvres of heavy vehicle drivers at-fault were connected with difficulties of changing or crossing the lane (Hanowski, Olson et al. 2006). Furthermore, these differences in primary manoeuvres were reflected in the incident types; incidents where light vehicle drivers were at-fault were associated with stopping or decelerating, whereas heavy vehicle drivers' at-fault incidents were associated with changing lanes and crossing the lane line. In this respect, it is interesting to note the findings from a site based naturalistic study of lane change behaviour in which the results showed that lane changes for heavy vehicles were shorter than for passenger cars (Toledo and Zohar 2007) (see also section 5.5).

While these results clearly show that naturalistic driving studies can be used to investigate interaction between light vehicles and heavy vehicles, they also show that there are some challenges concerning interpretation of the driver not driving the subject vehicles.

5.7 Driver characteristics and states

The previous section focused on naturalistic driving observation as method for investigating driver behaviour of, and interaction between, drivers of different types of vehicles. However, the method is also valuable with regard to investigating behaviour of *different types or groups of drivers*. Epidemiological research consistently shows that young and elderly drivers are at increased accident risk, drivers suffering from various chronic diseases have been found to have increased accident risk, driving under the influence of alcohol or other substances are associated with increased risk, whereas there is somewhat more mixed evidence with regard to if and how mental diseases affect driving behaviour and risk.

Naturalistic driving studies are suitable for investigating driver behaviour and accident risk associated with some driver characteristics and states, such as for instance young and elderly drivers and drivers with various health conditions, whereas the method is less suitable for investigating for instance driving under the influence of alcohol or other substances. In particular, even though it is assumed that the unobtrusive nature of naturalistic observation is quite resistant to observer effects (Dingus, Klauer et al. 2006), one has to expect that drivers will desist from extreme behaviours when participating in a naturalistic study, like driving under the influence of alcohol.

As for different driver age groups, previous naturalistic driving studies have typically investigated young driver behaviour (Prato, Toledo et al. ; Lotan and Toledo 2005; McGehee, Raby et al. 2007). In a study by Lotan and Toledo (2005), data from four young drivers and their parents were investigated in order to test the impact of a) participation in a program called Green Light for Life, and b) the type of feedback drivers received from the system. Importantly, the system used is designed to measure driver behaviour as such, not necessarily connected to crashes or incidents. Moreover, based on the driving performance measured, the system designates the drivers as safe, unsafe, or dangerous. The results of this small study showed that young drivers generated more events (i.e. risky behaviours) per hour compared to their parents. In particular, they generated more turn-handling events indicating unsmooth turns, and higher rates of lane-handling events than their parents. However, the parents showed higher rates of braking and acceleration events than the young drivers.

Prato et al. (in press) report on a similar study where 62 families with young, novice drivers were observed for a 12-month period of their graduated driver licensing program (GDL). The first three months of the observation was a so called ‘accompanied’ period followed by nine months of solo-driving. Risk indices were calculated for each driver based on various performance measures observed by means of the same in-vehicle data recorder (IVDR) system as described in the previous paragraph (Lotan and Toledo 2005; Toledo and Lotan 2006; Toledo, Musicant et al. 2008). The risk index levels increased significantly after the first three months, i.e., when starting the solo driving. Moreover, the risk index level of male young drivers was significantly higher than for females. Significantly increased risk indices were also found for sensation seekers, when driving solo at night, and when parents' driving was risk-prone (Prato, Toledo et al. in press).

Another naturalistic study investigating driver behaviour of young drivers was conducted by McGehee et al. (2007)[5]. The results indicated that the young drivers in the study could be grouped into two: those who were involved in few safety-related events (18 drivers) and those who were involved in many safety-related events (7 drivers).

These studies clearly show the potential for studying driver behaviour of young drivers by means of naturalistic driving observation. In particular, the findings in the study by Prato et al. (in press) support previous findings with regard to differences between boys and girls and the increased risk taking by sensation seekers. However, there are some limitations present in the studies, warranting further research in this area. For instance, the study by Lotan and Toledo (2005) as well as Prato et al. (in press) would be improved if video cameras were included in the data recording equipment. In this way, one could investigate behaviours at the operational level that are assumed to be more frequent among young drivers than more experienced drivers, as well as more tactical behaviours such as engaging in secondary or tertiary tasks while driving. Moreover, with larger samples of young drivers one could get data on accidents and near-accidents allowing for both statistical analyses of accident risk as well as more in-depth analyses of behaviour preceding accidents. Finally, an interesting issue would be to investigate behaviour, incidents and crashes dependent on type and amount of driving exposure.

As indicated above, naturalistic driving observation may also be used in order to investigate driving behaviour of drivers with various diseases or health conditions. However, in order to study such health implications for driving behaviour and accident risk, one needs a sample of drivers suffering from the disease in question. Alternatively, one can administer a self-report questionnaire to all participant drivers and have them indicate any diseases or mental health issues they are suffering from.

In a study by Silverstein et al.(2009) patients with dementia participated in a naturalistic driving study. The objective of this study was to investigate driving behaviour of persons with dementia, and compare these objective empirical data with the perspectives of the patients themselves, family member and driving specialists. Twelve such triads were investigated. The feasibility of using in-vehicle data collection for this purpose was demonstrated. Moreover, the validity of multiple forms of assessment of driving skills was compared to actual driving skills, and provided insight that can better inform decision-makers about appropriate intervals for checking driving competence. No further results are reported.

To our knowledge, no studies have investigated mental health conditions and driving behaviour by using naturalistic driving observation. One way to approach this issue could be to use validated test batteries for identifying various mental conditions in the sample, and compare driving behaviour and involvement in incidents and accidents between participants.

[5] This study is further discussed in section 5.8 'Applied use of ND'.

5.8 Applied use of naturalistic driving observation

Whereas the naturalistic driving observation obviously has great potential as a research method, such observation of drivers is also of applied value in itself. That is, naturalistic observation may be used as a tool providing feedback to drivers about their driving behaviour. In turn, such feedback, potentially in combination with some guidelines for safe driving, can serve as a basis for changing driver behaviour.

Using naturalistic driving observation as a tool for providing feedback to drivers is perhaps particularly interesting when it comes to young, novice drivers. The driver training or the graduated driver licensing are periods in which feedback about the young drivers' behaviour can be provided in combination with training and courses. Such feedback to young drivers has been tested recently Prato, Toledo et al. in press; Lotan and Toledo 2005; McGehee, Raby et al. 2007: Fylan and Fylan 2009). In the most recent of these studies, the vehicles of 62 families were equipped with an IVDR system (in-vehicle data recorder) allowing for observation of more than 20 driving maneuvers. In each of the 62 families, there was a young, novice driver, and the observation began as she or he passed the driving test and started the graduated driving licensing program (GDL). The families were observed for a 12 month period; feedback started after month 4 or 5. The feedback could be checked on a web-site in which each participant entered a personal access code. Feedback was given as the calculated risk indices for each driver. The results concerning the feedback showed that the risk indices seemed to decrease substantially when the first feedback was available for the participants (Prato, Toledo et al. in press). For girls, the risk index level obtained after the first feedback more or less remained, whereas the risk level increased again for boys. Moreover, a differentiated effect of feedback was found when looking at who received/checked the feedback; risk indices decreased when parents monitored the driving behaviour of their children, but increased when young drivers themselves entered the web-site (Prato, Toledo et al. in press). This is interpreted to imply that parents who check their children's driving records are more active in monitoring their children and perhaps impose more restriction on their behaviour. Another interesting finding was that parents risk indices were consistent throughout the period, i.e., not affected by feedback, indicating that parents' driving behaviour is well established.

In another study, feedback to teen drivers on their driving by means of an event-triggered video device, and subsequent parental feedback was evaluated by McGehee et al. (2007). Both immediate and delayed (parental) feedback on teen driving behaviour was given, but there was no opportunity to differentiate between the two types of feedback in the study. The results from a base-line phase indicated that the participants in this study could be grouped in two: those who were involved in few safety-related events (low frequency group) (18 drivers) and those who were involved in many safety-related events (high frequency group) (7 drivers). In the intervention phase, the low frequency group more or less maintained their behaviour with regard to safety-related events, whereas there was a large and significant drop in safety-related events for the high frequency group. Also, seat belt use increased from 81.8 percent to 96.9 percent. Long term effects were not reported in the article, but the authors state that data would be gathered in order to measure long-term effects as well.

These two studies show the potential of using naturalistic driving observation as feedback. Importantly, the feedback seem to have a better effect on young, novice drivers compared to adult drivers who have established a driving style. The studies differ somewhat with regard to the differentiated effect on "risky drivers" versus more safe drivers. The study by Prato et al. (in press) shows that the feedback had best effect on girls (who were safer in terms of risk indices than boys); their level of risk indices remained quite low after the feedback whereas boys' risk indices increased during the subsequent months after the feedback. The study by McGehee et al. (2007) indicates that feedback has best effect on the "risky drivers". However, the latter study only focused on short term effects, whereas the study by Prato et al. looked at effects over a 12 month period.

Results from Fylan and Fylan (2009) show that young drivers participated in a pilot programme including observation because their parents had encouraged them to, because they wanted to improve their driving and gain experience, because they wanted to find out what type of drivers they were, and to prove to others that they were safe and responsible drivers. Main barriers for participating (reported by the participants) were concern for parents monitoring their driving, discussing the results of the programme, and the possibility that they were being checked or spied upon.

As for benefits of having a youngster in the program, parents reported that it gave them reassurance and peace of mind that their child was safer on the roads.

The self-report findings also showed that all but one of the young drivers discussed the feedback with their parents and that they found it easy to do so (Fylan and Fylan 2009).

The differentiated potential of naturalistic driving observation as a tool among different types of young novice drivers should be investigated further. Moreover, applied research should be conducted in order to investigate the potential for using naturalistic driving observation as a tool in driver training courses. However, naturalistic driving could also be used as a tool with respect to elderly drivers who want to assure that their driving is not impaired. Elderly drivers are at increased accident risk, and initiatives are taken to improve their safety by giving courses. Elements of naturalistic driving could be used in such courses.

5.9 Eco-driving

Naturalistic driving observation has gained field within traffic safety research the last 10 years. The method should not, however, only be considered relevant for studying traffic safety issues. One area in which naturalistic driving observation may prove to be valuable is within the field of environmentally friendly driving. So called eco-driving or green driving denotes a smart and smooth driving style that is assumed to reduce fuel consumption and greenhouse emissions. More specifically, eco-driving is characterised by (a) shifting to a higher gear as soon as possible, (b) maintaining a steady speed, (c) keep high gear and low rpm (d) anticipate traffic flow, and (e) decelerate smoothly (*www.ecodrive.org*).

In a study by Ericsson (2001), naturalistic data was used to investigate which factors in driving patterns have an effect on emissions and fuel-use. Fuel-use and emission factors were estimated for a subset of 5217 cases using two different emission models. Nine of the driving pattern factors had considerable effects on the various dependent variables, of which four were associated with aspects of power demand and acceleration, three described aspects of gear-changing behaviour and two described the effect of various speed intervals. Thus, naturalistic driving observation can be used to identify the important factors that affect fuel-consumption and emission, knowledge that is important with regard to developing guidelines for how to optimise driving from an environmentally friendly perspective.

In many countries, knowledge about how to best drive environmentally friendly is applied in various eco-driving courses, and more regular driver training courses. Af Wåhlberg (2007) evaluated an ecodrive course for heavy vehicle drivers in a bus company in Sweden. More specifically, the following research objectives were addressed: 1) study the long-term effects of training in fuel-efficient driving on fuel consumption, accident rates and acceleration behaviour, and 2) study the effect of technical feedback on the same three parameters. All in all, the results indicated little or no long-term effects of driver training on the measured variables. A reduction in fuel consumption of about two percent (mean over 12 months after training) was found. No effects were found for accidents. In the second phase of the experiment, the effect of technical feedback during driving was investigated, and the results showed a further reduction of about two percent.

Long-term effects of an eco-driving program was also evaluated by Beusen et al. (2009). In this study, participants driving equipped cars were observed for about 10 months with an eco-driving course after the first 4 months. The main objective of the study was to investigate eco-driving by means of an on-board logging device and investigate potential effects of the course by looking at fuel consumption and driving behaviour parameters. The results indicated that the average reduction in fuel consumption after the eco-driving course was 5.8 percent, however with large differences between individuals. Moreover, driving behaviour parameters reflected the changes in fuel consumption; gear shifting point during acceleration moved closer to the optimal, distance driven while coasting increased, fewer heavy accelerations and decelerations occurred, and distance driven at steady speeds using optimal gear increased. Importantly though, 20 percent achieved no fuel savings.

5.10 Site-based naturalistic studies

In a typical naturalistic driving study vehicles are equipped with devices that record the behaviour and performance of the driver. This is primarily done in order to investigate the behaviour of the driver, and this information can be linked to the vehicle and the driving environment. This information is, however, limited with regard to saying something about vulnerable road users.[6] An alternative 'naturalistic observation study' for investigating vulnerable road users can be conducted by means of a so called site-based naturalistic study. Moreover, site-based studies are not limited to investigating vulnerable road users, but can be used to investigate driver behaviour as well. Two studies, one focusing on the interaction between vulnerable road users and vehicle drivers and one focusing on drivers' speed when approaching an intersection, will be reviewed here.

In a study by Phillips et al. (2007) it was aimed to use naturalistic driving to explore an important addition to the list of dimensions that can be used to predict cycle path effects, that of learning and adaptation by those road users regularly encountering the cycle path. A total of 57 hours of video registrations were made of interactions between cars and bicycles at a Norwegian road-cycle path intersection, 2, 50 and 120 months following junction alteration. The alteration was the introduction of a cycle path across a side road leading from a housing estate to a main commuter road. Many of the road users using the junction could be considered as routine users. The interaction events were defined by a video analyst as either yielding (slow braking and/or turning to avoid other road user) or conflict (harsh braking and/or turning to avoid other) events.

A significant decrease in overall conflict levels was found four years after introduction of the cycle path (from 3.0 to 0.7 per cent of interactions resulting in conflict), and a subsequent decrease between four and ten years (from 0.7 to 0.4 per cent) was close to significance. The decrease in conflict was mirrored by an increase in the number of those give-way events not resulting in conflict. The give-way and conflict situations registered were classified according to eight possible intersection scenarios, and compared over time to the yielding behaviours of drivers and cyclists in each scenario. Those scenarios in which no conflicts occurred in over 28 hours of registrations ten years following path introduction were the very same scenarios in which significant changes in driver yielding behaviour was detected between four and ten years following path introduction

In a study by Liu (2007) site-based observation method was used to study drivers' speed when approaching an intersection. More specifically, speeding violations when approaching an intersection were studied in relation to age, gender, vehicle type, traffic light status, site (urban vs. suburban), rush-hour-status, passenger status, and weather. The results indicated that the major contributing factors for approaching speed were site, rush-hour-status, traffic light condition, vehicle type, and driver gender. Moreover, a binary logistic regression indicated significant site and rush-hour effects on speeding, with the risk of violation of speeding in the suburbs nearly six-fold that in urban areas. Also, the relative risk of speeding during non-rush hours was three times

[6] To some extent interaction between equipped vehicles and vulnerable road users can be studied by selecting incidents from the recorded material in which the subject vehicle interact with other, vulnerable, road users.

higher than that during rush-hour. Finally, male drivers under 55 years of age had the largest speeding propensity.

Finally, site-based studies can be used to investigate traffic flow and traffic management. Toledo and Zohar (2007) used a site based study to investigate duration of lane changes.

As these studies show, site-based studies can be valuable supplements to in-vehicle studies. Site-based studies are particularly valuable with regard to observing vulnerable road users and such road users' interaction with motorized vehicles. Moreover, drivers' behaviour at a specific junction or road section can be analysed with regard to saying something about the road segment in question.

This can be further explored if combining site based and in-vehicle studies; e.g., setting up a video-camera at a site where it is known that drivers in the in-vehicle study often drive. By use of continuous recording of vehicles' position by GPS in the in-vehicle equipment, data recorded from outside vehicles with the traffic situation (site-based) and inside-vehicle can be coordinated and incidents may be analysed from various perspectives.

5.11 Naturalistic driving and self-report measures

One of the main benefits of naturalistic observation is the objective nature of the observation performed. As discussed in paragraph 2.1.2, self-report measures can be subject to various biases such as forgetting, social desirability, incomplete information available, etc., and naturalistic observation is believed to alleviate some of the problems associated with these biases. Combining self-report measures and naturalistic driving observation allows for investigating the relationship between the two types of measurement, as well as using self-report measures to differentiate between different types of drivers. The following research objectives are relevant in this respect:

- Compare self-report of driver exposure to actual driver exposure
- Compare self-report of involvement in crashes/incidents with driver behaviour and actual involvement in crashes/incidents
- Validation of standardized driver behaviour questionnaires/test batteries by comparing self-report and objective measures
- Compare driving behaviour of different drivers based on self-report measures
- Compare involvement in crashes/incidents of different drivers based on self-report measures

The first three objectives listed above, concern validation of self-report measures, or perhaps more correctly the observed correspondence between self-report measures and objective measures. Regarding the first of the objectives, the validity of self-report measures of driving exposure and driving patterns has been questioned. A comparison of self-report measures of driving exposure with patterns of objective measures was conducted in a study by Blanchard et al. (in press). More specifically this was done in a sample of elderly drivers. Drivers were not encouraged explicitly to self-report kilometres driven and only 53 percent attempted to do so. These self-reported estimates turned out to be inaccurate when compared to the objective measures. Further on, drivers tended to miss a significant number of trips and stops in their diaries. However, driving behaviour over the week was fairly consistent with usual practices regarding time of day, driving in certain areas, and night driving.

In a study by Toledo et al. (2008) where behaviour of drivers were measured by means of an in-vehicle data recorder and risk indices for each driver were estimated, analyses were made in order to study if self-report of crashes were correlated to risky driving. The results indicated that the risk profiles were in fact correlated with actual crash history of the drivers.

The two last research objectives listed above concern the use of self-report measures to get information about individuals that is not available through objective observation. Measures of interest are hypothesized to be associated with driving behaviour or crashes/incidents. In turn, comparison of behaviour or involvement in crashes or incidents can be made between drivers who differ on the variables of interest. Such variables of interest can for instance be descriptive background variables such as age, gender and socioeconomic status, variables describing a physical or mental health condition, life stress measures, personality traits, attitudes or more concrete driving behaviour variables.

In the 100-car study, two research questions were addressed in relation to distractive activities and self-report measures: (1) What is the relationship between measures obtained from pre-test batteries and the frequency of engagement in distracting behaviours while driving?, and (2) is there any correlation between willingness to engage in distracting behaviours and measures obtained from pre-test batteries? (Klauer, Dingus et al. 2006). The results showed that drivers who had high involvement in inattention-related crashes were younger and had less driving experience than drivers with low inattention-related crashes (Klauer, Dingus et al. 2006). Also, high-involvement drivers reported more traffic violations and involvement in crashes prior to the actual study. In addition they were more often drowsy and were different on various personality measures than the low-involvement drivers.

In the study by Prato et al. (in press), the results indicated that drivers high on sensation seeking (measured by self-report) had a higher risk index level than drivers low on sensation seeking.

While in-expensive and with the potential of reaching many participant subjects, self-report measures are consistently questioned because of the subjective nature and potential for various biases. The naturalistic driving studies cited in this section do not show clear support for the validity of self-report measures, although, for instance, there is a correlation between risky behaviour and self-reported crash involvement (Toledo, Musicant et al. 2008). Further, and more systematic research, addressing the issues of correspondence between self-report measures and objective measures obtained by use of naturalistic driving should be conducted.

5.12 Infrastructure and environmental factors

In a typical naturalistic driving study, it is emphasised that the nature of the method allows for investigating the relationship between driver, vehicle and environmental factors, such as the road, traffic situation, geographic area, weather, time of day etc. In order to investigate environmental variables, one needs equipment such as for instance GPS and video of the forward, backward and/or side of the subject vehicles. This is standard in most naturalistic driving in-vehicle equipment.

Although there is a potential for studying infrastructure and environmental factors in most naturalistic driving studies, this has not been a main issue in the literature. However, in the 100-car naturalistic study, for instance, analyses were made in order to address the question of driver inattention under different environmental conditions (Klauer, Dingus et al. 2006). As for drowsiness, the results showed that a higher percentage of drowsiness-related baseline epochs were present during free-flow traffic on divided roadways, and areas where roadway junctions were absent. As for secondary tasks, all environmental conditions resulted in increased risk when engaging in complex tasks.

Moreover, in the upcoming SHRP2 project, infrastructure and environmental factors are important topics in focus, such as roadway (edge-marking, rumble strips, lane width, shoulder type and width, curvature, grade, signage, and sight distance), intersection (with signals vs. without, configuration, signal timing, traffic volumes and sight distance) and environmental factors (light, weather, pavement).

Future naturalistic driving studies should address the issues of infrastructure and other environmental factors in order to aim towards a more thorough picture of the relationship between drivers, vehicles and roadway/environment.

6 Conclusions

The main aim of this document was 1) to discuss naturalistic driving observation and compare this method to other more traditional methods for studying driver behaviour and crashes, and 2) to review the literature on naturalistic driving observation. With regard to the second aim, various fields that can be, and have been, investigated by use of naturalistic observation were identified, and studies discussed. The aim of this part of the review was to lay the ground for potential new research questions and fields that potentially would gain from being studied by means of naturalistic observation.

6.1 Discussion of methods

The main advantages (+) and problems (-) associated with experimental research with various degrees of experimental control are:

- Experimental control allowing for causal explanations (+)
- Direct observations (+)
- Artificial study settings/low ecological validity, limited generalisation (-)
- Observer effects (-)

Main advantages and problems with self-report studies, epidemiological studies, and crash database studies are:

- Large samples (+)
- Actual crashes (+)
- Self-report biases (-)
- Insufficient information about preceding factors (-)
- Indirect observations (-)

By using naturalistic observation, one is able to directly observe actual driving (like in simulation experiments) while avoiding the artificial experimental setting, while also making it possible to investigate actual incidents and crashes (like self-report or crash database studies) without relying on subjective information from participants. The strengths and weaknesses of naturalistic driving can be summarised as follows:

Methodological strengths:

- Direct observation
- High ecological validity

- Unobtrusive
- Long duration
- Objective observations
- Generalisation of results
- In-depth information about factors contributing to accidents

Methodological weaknesses:

- Low internal validity with respect to causal explanation, low control over external variables
- Potential for biased samples
- Potential for observer effect
- Resource demanding (sample, duration, data gathering, data storage, data analysis)

6.2 Review of the literature

The results from this literature review[7] show that the following areas or fields have been studied by use of naturalistic driving methods:

- Driver distraction and inattention
- Drowsiness and fatigue
- In-vehicle systems
- Lane change behaviour
- Heavy-vehicle – light-vehicle interaction
- Driver characteristics and states
- Applied use of naturalistic driving – e.g., in driver training and graduated driver licensing programs

In particular driver distraction and inattention have been studied quite extensively by use of naturalistic driving observation, and this is probably because by using this method there is great potential for gaining new and valuable knowledge about relative risks and population attributable risks associated with various distractive activities. In-vehicle systems, on the other hand, have been studied to a lesser degree in pure naturalistic studies, but are tested and investigated in large scale in field operational tests.

[7] Making the reservation that this is not a complete literature review and that other areas may have been addressed in naturalistic driving studies

In addition to the fields listed above that all concern road safety, the following fields have to some degree been studied by use of naturalistic driving observation:

- Eco-driving
- Traffic flow/traffic management (lane change behaviour)
- Relation between self-report and naturalistic observation

We have only been able to find a few naturalistic studies concerning eco-driving and traffic flow/traffic management. However, there is a large potential for addressing research questions related to these fields by using naturalistic driving observations, and this should be explored further in future naturalistic driving studies.

Taking a more scientific perspective, naturalistic driving observation also allows for investigation and validation of other more traditional methods for studying road user behaviour, such as self-report measures.

Summing up, naturalistic driving observation has great potential with regard to studying various important factors for road safety – the driver, vehicle, road, and traffic situation – and the interaction between these variables. By conducting a large scale naturalistic driving study, one can gain in-depth knowledge about normal driving behaviour and factors contributing to crashes and incidents, making it possible to generalise to a broader driver population.

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Appendix I: Summary of scientific peer reviewed papers and published reports

1 Modeling the behaviour of young drivers during the first year after licensure

Prato, C. G., Toledo, T., Lotan, T., Taubman, B-A.O. (in press). Modeling the behaviour of novice young novice drivers during the first year after licensure. *Accident Analysis and Prevention*, doi: 10.1016/jaap.2009.09.011

Objectives: In this study, the main objective was to investigate factors that affect the risk taking behaviour of young drivers by means of naturalistic driving observation. The following factors were investigated in relation to risk taking behaviour: gender, impact of parents through their own driving as well as monitoring of the young drivers, driving experience in accompanied and solo driving periods, driving experience at night, and sensation seeking trait.

Methods: 62 families volunteered to participate in the study and having their vehicles equipped with an in-vehicle data recorder device. The young drivers in each family had just the driving test when observation began, and they were observed for a 12 month period during their graduate driver licensing program (GDL). The first three month was a so called ‘accompanied period’ followed by nine months of ‘solo-driving’. Both young drivers’ and parents’ driving performance were recorded. Moreover, feedback was provided after approximately four months on a web-site in which both drivers and their parents could check their risk indices.

Results: The results showed that the risk index level differed between male and female young drivers, with higher risk indices among males than females. Moreover, the risk indices increased significantly after 3 months when entering the solo-driving period. However, it decreased again when feedback was provided between month 4 and 5. In contrast, parents’ driving profiles did not change during the 12 month period, indicating that their driving styles are well established. Moreover, a random effects binominal model was used to investigate what factors were associates with risk indices. Being male, solo driving, sensation seeking, having risk prone parents, and driving exposure at night were significantly associated with increased risk. On the other hand, having the parents monitor the feedback of the young drivers and driving exposure in the accompanied period were significantly associated with decreased risk indices.

Limitations: The IVDR-device does not include any cameras and potential engagement in secondary or tertiary behaviours cannot be observed.

2 Correspondence between self-reported and objective measures of driving exposure and patterns in older drivers

Blanchard, R.A., Myers, A. M., Porter, M. M.. (in press) Correspondence between self-reported and objective measures of driving exposure and patterns in older drivers. *Accident Analysis and Prevention*, doi: 10.106/j.aap.2009.09.018

Objectives: The validity of self-report measures of driving exposure and driving patterns has been questioned, and objectives measures of driving behaviour are called for. The main aim of the present study was to compare self-report measures of driving exposure and patterns with objective measures. More specifically this was done in a sample of elderly drivers.

Methods: 61 drivers from Southwestern Ontario participated in the study. 59 percent of the drivers were women, and the age ranged from 67 to 92, M=80.2, SD=5.5). All drivers drove at least once a week, and all drivers had many years of driver experience.

Self-report measures of driving behaviour and patterns included a driving habit questionnaire, two measures of self-regulation, trip logs, activity diaries and a follow-up interview.

Objective measures of driving behaviour and patterns were recorded using two types of in-vehicle logging systems; a device that can record up to 300 hours of driving information such as duration, distance and speed, and a lightweight GPS device that can record up to 320 hours of data. The latter of these devices can determine vehicle position (roadways, turns) when paired with digital maps.

Results: Drivers were not encouraged explicitly to self-report kilometres driven and only 53 percent attempted to do so. These self-reported estimates turned out to be inaccurate when compared to the objective measures. Further on, drivers tended to miss a significant number of trips and stops in their diaries. However, driving behaviour over the week was fairly consistent with usual practices regarding time of day, driving in certain areas, and night driving.

Limitations: One limitation regards the in-vehicle equipments' ability to identify who drove the vehicle. However, in this study participants had to b either the sole household driver or share one vehicle. Moreover, GPS recordings are subject to missing data from cold starts, and signal loss (in tunnels, underpasses etc.).

3 Driver distraction in commercial vehicle operations

Olson, R. L., Hanowski, R. J., Hickman, J. S., Bocanegra, J. (2009). Driver distraction in commercial vehicle operations. Report No: FMCSA-RRR-09-042. U.S. Department of Transportation, Federal Motor Carrier Safety Administration, Washington D. C.

Objectives: The main objective of this study was to investigate driver distraction among commercial vehicle operations using naturalistic driving data. More specifically, the following research questions were addressed:

- What are the types and frequency of tasks which drivers engage in prior to involvement in safety-critical events? What are the odds ratios (OR) and the population attributable risk (PAR) percentages for each task type?
- What environmental conditions are associated with driver choice of engagement in tasks? What are the odds of being in a safety-critical event while engaging in tasks while encountering these conditions?
- What are the odds ratios of eyes-off-forward-roadway? Does eyes-off-forward-roadway significantly affect safety and/or driving performance?

Methods: Data from two previous naturalistic studies – a field operational test of driver drowsiness warning system (DDWS) (Hanowski 200(8) and a naturalistic truck driving study (Blanco in press) were combined and analysed. Combined, the two data sets represented 203 commercial vehicle drivers, and approximately 3 million miles of data including kinematics and video data.

In the DDWS study, 103 drivers participated of which one was female. The age ranged from 24 to 60, with an average of 40. The DDWS study used an experimental design, and 24 participants were randomly assigned to the control group whereas 79 drivers were assigned the experimental group. One important inclusion criteria, in addition to not wearing glasses and passing a vision and hearing test, was that a significant part of the participants' driving was performed at night. Each driver drove an average of 12 weeks.

In the naturalistic driving study, 100 truck drivers drove instrumented vehicles, of which 95 were males and 5 were females. The average age was 44.5 ranging from 21 to 73 years. This was not an experiment, as the DDWS was.

In both studies, data was recorded by means of dynamic performance (kinematics), video and audio. The dynamic performance measures included longitudinal and lateral acceleration and braking, the video included view of the drivers face, as well as forward and backward (left and right) roads. Experience from the DDWS indicated that it could be wise to have yet another camera covering the lap/hands of the driver as this would help identify some of the distracting activities the drivers were engaged in – such a camera was included in the naturalistic truck study. The audio was to be started by the driver if he/she pressed an Incident box so he or she could comment on an incident.

Trained data analysts identified so-called safety critical incidents defined as crash, near-crash, and crash-relevant conflicts. This was done by running the data through a software programme in which incidents were flagged based on certain thresholds: longitudinal acceleration (hard-braking), time-to-collision, swerve, critical incident box and analyst identified. For each safety-critical incidents, the analyst defined type of conflict, potential distractions, driver behaviour, and road and environmental conditions.

Results: 4452 safety-critical events were identified in the dataset. Of these, 21 were crashes, 197 were near-crashes, 3019 were crash-relevant conflicts, and 1215 were unintentional lane deviations. In order to be able to estimate odds ratios, baseline events were also gathered, i.e., uneventful, routine driving. Thus, 19888 baseline epochs of normal driving were randomly selected. Moreover, the total amount of time a driver was in the study was used to weight the frequency of baseline epochs per driver.

In 81.5 percent of all safety-critical events some type of distraction was listed as a potential contributing factor. However, this is following the procedure of Klauer et al. (2006) in the 100-Car study in which any task that was present preceding the incident – including secondary tasks that can be defined as driving-relevant inattention such as checking the mirror. Defining distraction as tertiary tasks, i.e., not driving-relevant distractions such as texting, eating etc., a distraction factor was present in 59.9 percent of all safety-critical incidents, and 63.9 percent of incidents in which the subject driver was at-fault.

Odds ratios were estimated for various distractions, including complex tertiary tasks, moderate tertiary tasks, simple tertiary tasks and secondary tasks. The highest risk was associated with texting on cell phone (OR=23.34, 95%CI 9.69, 55.73), followed by other complex tasks (cleaning side mirror etc.) (OR=10.07, 95%CI 3.10, 32.71) and interact with/look at dispatching device (OR=9.93, 95%CI 7.49, 13.16). Interestingly, talking or listening to a hand-held phone was not significantly associated with increased risk, whereas talking/listening to a hands-free phone or a Citizen Band radio was associated with decreased risk, i.e., had an protective effect.

In addition to odds ratios, population attributable risks were estimated. This estimate considers not only the odds ratio (i.e., how risky it is), but also the frequency of the various distracters. Thus, even though a distracter has a high odds ratio, it may be so rare that eliminating the distracter would not reduce crashes. The distracters with the highest population attributable risk were 'interact with/look at dispatching device', 'dial cell phone', 'read book/newspaper/paperwork', and 'look at map'.

Moreover, the results clearly show that the tasks associated with the highest risk are those in which the drivers' eyes are drawn away from the forward roadway. Texting for instance, had the highest odds ratio and was also the task where the duration for eyes off the forward road was highest (4.6 seconds over a 6 second interval). Eye glance analyses also showed that long glances away from the forward road was associated with increased risk (OR=1.3) and very long glances (i.e., more than 2 seconds) had the highest risk (OR=2.9). Interestingly, very short glances of less than 0.5 seconds were also significantly related to increased risk (OR=1.36) among these commercial vehicle drivers.

Limitations: The present study's main aim was to investigate distraction factors among commercial vehicle drivers. One type of distraction that has been emphasised in the literature on driving distraction is "cognitive distractions". In the present study it was difficult to obtain a measure of such cognitive distraction, due to the naturalistic nature of the study as opposed to a controlled study.

Another limitation regards few observation of some of the distracters, making it impossible to conduct statistical tests on potential interaction effects.

Also, the lack of continuous audio data is a limitation. Such data could make it possible to identify voice-activated dialling and subsequent hands-free conversations, which could not be investigated in the present study.

4 Evaluating the 2003 revised hours-of-service regulations for truck drivers: The impact of time-on-task on critical incident risk

Hanowski, R. J., Hickman, J., Olson, R. L., Bocanegra, J. (2009). Evaluating the 2003 revised hours of service regulations for truck drivers: The impact of time-on-task on critical incident risk. *Accident Analysis and Prevention*, 41, 268-275.

Objectives : See Hanowski (2007) for description of the HOS revision in 2003 in US. This paper sets out to evaluate the effect of extending time-on-task from 10 to 11 h in terms of fatigue as a cause of critical incidents. Available research evidence is described as mixed.

The questions are thus

- How does time-on-task influence risk for a critical incident?
- How does time-of-day influence risk for a critical incident?
- The aim is to provide key information for the evaluation of HOS policy.

Methods: The method is described in Hanowski et al. (2007) and in more detail in the FOT report (2008). Because Hanowski et al.(2007) report analyses of an incomplete data set, the numbers are different in this article, which is based on the complete data set.

There were 103 driver participants and no team drivers. Loss of data from several of the participants is described, mostly due to sensor faults.

The drivers were assigned test-trucks, which they drove for an average of 12 weeks. The number of companies involved is not reported. 46 trucks were used with data acquisition systems installed, as described in Hanowski et al. (2007). The kinematic sensor data was recorded at 10 Hz, the video at 30 Hz. Each DAS unit was bench tested before installation and after.

The data were downloaded every 2-3 weeks and the instruments serviced and the data checked for anomalies indicating sensor malfunctions.

This is “the largest naturalistic driving study ever” with 2.3 million miles of driving data (but since the only trigger for data recording was the ignition key, it is perhaps not the most efficient!).

Critical incidents were identified and categorised as described in Hanowksi et al. (2007). Preliminary threshold values trigger variables used to decide which incidents are selected from the data recorded were set based on previous studies (100-car study) and then modified based on crash natures from the current data set.

These trigger types were longitudinal acceleration thresholds, time to collision, swerve values, depression by driver of critical incident button, and extra incidents identified by data reductionist viewing video footage.

Whether the subject drivers are at-fault for a particular critical incident was assessed using the so-called critical reason (no further details but reference given).

The driving hour and time of day was assigned to each critical incident and risks of incidents at a given hour calculated using odds ratios.

Results: The article highlights three analyses, The first analysis is fairly representative of the others in that it involves looking at 819 critical incidents, including 12 crashes, 12 tyre-strike crashes, 85 near-crashes and 710 crash-related conflicts.

All critical incident frequencies were normalised using the exposure unit 'total opportunity for a critical incident' during a driven hour. This was effectively the number of trips ongoing during that hour. This was necessary because different numbers of trips were reported for different times of the day and at different successive hours in a shift.

Mapping the incidence of incidents for which the driver was at-fault across each of the eleven hours of a driving shift, it is found that there is a spike of critical incidents in the first hour of the shift. Surprisingly, at-fault critical incidents are 1.73 times more likely to happen in the first hour than in the eleventh hour of the shift.

Analysis of incidents involving exclusively those drivers who drove up to the eleventh allowable hour (about a third of drivers did this) gave the same results.

Importantly, in terms of the HOS regulations introduced, there was no statistical difference between the frequency of incidents occurring in the tenth and eleventh hours.

Mapping of incident occurrence according to time of day resulted in a pattern that was closely correlated with increases and decreases in traffic volume as measured in a previous 1995 study. In other words, the frequency of incidences did not peak at times when fatigue was expected to peak (early hours of morning). This is not surprising given the number of factors other than fatigue that contribute to cause critical incidents.

Implications: There is no increase in critical incident occurrence with time-on-task.

Critical incidents are lower in the night in naturalistic driving. This is important in relation to ongoing recommendations against night-time driving.

The high frequency of incidents in the first hour may be caused by sleep inertia (the driver is still waking up), certain road type at the beginning of a journey, or higher traffic density at the beginning of a journey.

Limitations: Authors themselves recommend caution in generalizing from this data, based on a small number of drivers. This leads to a point that can be made about most of the ND articles addressing fatigue. There is a need to consider the limitations of the method in terms of scale and a need for recommendations about future work to that address either solving the scale problem or using other methods (perhaps this work has already been done?) to support the results reported.

Large resource demands on data reduction meant that the events were validated by only two researchers (three in Hanowski et al., 2007).

Is there a need for a critical incident button? Does the driver ever press it when no other trigger thresholds are exceeded? This would be useful to know (because the button is non-naturalistic!).

The authors point out that the study lacks records of non-driving work activity and a way to separate non-driving work from rest breaks. Breaks less than ten minutes are also ignored and counted as driving time.

Were the night incidents, albeit less likely, more severe? This is not accounted for in this study. It is likely that those incidents occurring in greater traffic are less severe.

The result that at-fault critical incident risk does not appear to increase along with time-on-task must be carefully interpreted before making implications to organizations and drivers. It is possible that the risk for a certain type of incident or crash increases with time-on-task, but that this is masked by factors which reduce the risk of other incidents.

The current analysis does not focus on fatigue-linked incidents.

5 Monitoring drivers with dementia: An instrumented vehicle study

Silverstein, N. M, Eby, D. W., Molnar, L. J., LeBlanc, D.J., Adler, G. (2009). Monitoring drivers with dementia: An instrumented vehicle study*. Alzheimer's and Dementia,* 5, 140-140.

Objective and methods: Even though dementia affects many skills needed for driving, up to 45 percent of persons with this disease continue to drive. The objective of this study was to investigate driving behaviour of persons with dementia, and compare these objective empirical data with the perspectives of the patients themselves, family member and driving specialists. 12 such triads were investigated.

Results: The feasibility of using in-vehicle data collection for this purpose was demonstrated. Moreover, the validity of multiple forms of assessment of driving skills was compared to actual driving skills, and provided insight that can better inform decision-makers about appropriate intervals for checking driving competency.

6 Using on-board logging devices to study the longer-term impact of an eco-driving course

Beusen, B., Broekx, S., Denys, T., Beckx, C., Bart, D., Maarten, G. et al. (2009). Using on-board logging devices to study the longer-term impact of an eco-driving course. *Transportation Research Part D: Transport and Environment,* 14, 514-520.

Objectives: In this study, on-board logging devices were installed in the cars of several drivers in order to study (eco) driving behaviour and fuel consumption. Drivers were followed for a 10 month with an eco-driving course after the first 4 months. The main aim of the project was to investigate eco-driving by means of an on-board logging device (i.e., naturalistic observation), in particular, potential effects of an eco-driving course was studies by looking at a) fuel consumption and b) driving behaviour parameters

Methods: The on-board logging device is small and installed out of the driver's sight. It includes a memory card, a GPRS-modem, a GPS tracking system, and is connected to the controller area network (CAN) of the vehicle. Two types of data can be recorded: the position and speed of the vehicle (GPS) and electronic engine data (CAN-bus) (data on mileage, number of revolutions per minute, position of the accelerator pedal, gear selection, instantaneous fuel consumption and engine coolant temperature)

The experimental design is a before-after study. After four months, respondents participated in a four-hour fuel-efficient driving course.

Although on-board logging devices were installed in several cars (30), eligible data were only available for 10 cars. Respondents were recruited internally at VITO (the Finnish institute for technological research), and in a car magazine.

Results: Results indicated that the mean changes in fuel consumption after the eco-driving course was a reduction of 5.8%, however with large differences between individuals. Moreover, driving behaviour parameters reflects the changes in fuel consumption; shifting point during acceleration moved closer to the optimal, distance driven while coasting increased, fewer heavy accelerations and decelerations occurred, and distance driven at steady speeds using optimal gear increased. Importantly though, 20 percent achieved no fuel savings.

The study demonstrates the applicability of using an on-board logging study (naturalistic observation) in order to study eco-driving.

Limitations: Although not discussed, there are some limitations that should be mentioned. First, the sample is rather small and firm results are hard to make based on such a small sample. Second, the study would improve considerably including a control group not attending the eco-driving course. Finally, the participants in this study might be motivated beyond normal to learn and engage in eco-driving, as they volunteered to be part of this project, indicated by the fact that 40 percent of the participant reduced the fuel consumption even before the eco-driving course.

7 In-vehicle recorders for monitoring and feedback on drivers' behaviour

Toledo, T. Musicant, O., Lotan, T. (2008). In-vehicle data recorders for monitoring and feedback on drivers' behavior. *Transportation Research Part C: Emerging Technologies,* 16, 320-331.

Objectives: The main aim of the present study was to investigate driving behaviour using an in-vehicle recorder. More specifically, the following research aims were addressed:

- Investigate the applicability of the IVDR to measure and impact driving behaviour
- Investigate if risk indices based on the driving behaviour are correlated to past crash involvement.
- Investigate whether feedback to drivers about their own driving behaviour and risk profile has effect on subsequent driving behaviour.

Note that the present study only investigated driving behaviour as such, not specific incidents or accidents. However, it was sought to identify potential relationships between driving behaviour and previous accident involvement.

Methods: 191 vehicles in a single company were installed with so called in-vehicle data recorders (IVDR). The average age in the sample was 41 and ranged from 25 to 68. Each vehicle was driven by one specific employee in the company, and the participants were not professional drivers. Data was first gathered throughout 8 weeks without giving participants further information than that the IVDR was safety equipment. The driving behaviour identified in this period served as the baseline behaviour of the drivers. After 8 weeks, the drivers received feedback on their driving, and were allowed access to the web-site in which they could observe the feedback on their own driving behaviour.

The overall framework of the IVDR system comprises four different tasks: 1) measurement (driver and vehicle identification, trip start and end, longitudinal and lateral accelerations, vehicle speed, and vehicle location), 2) detection (pattern recognition algorithms applied to the raw measurements to detect maneuvers, such as lane changes, turns, sudden brakes, strong accelerations, excess speed etc. – these maneuvers are further categorised according to their severity level, among other things), 3) analysis (individual risk index, risk classification, trip-level risk index and classification, speed index, fuel consumption, and exposure measures statistics), and 4) feedback (real-time or delayed). In addition, information about the drivers' past involvement in car crashes were collected (from company records), including 'all crashes', 'fault crashes' and 'record period'.

Results: Results indicated that the risk profiles were correlated with actual accident history of the drivers, and that driving behaviour – measured as ”risk indices” or “profiles” changed in the 7 months following exposure to the feedback. It is emphasised, though, that this is only to be regarded as a short term effect. Previous research has found risk behaviour to increase after longer periods of time. Also, the results showed a significant reduction of about 38 percent in crash rates from the period before to after the feedback. A similar reduction was not found, however, when looking at at-fault crashes only.

Limitations: The IVDR system used in the present study did not include video, excluding the potential for examining driver distractions, eye glances, forward or backward roads, environmental factors etc.

8 A method for evaluating collision avoidance systems using naturalistic driving data

McLaughlin, S. B., Hankey, J. M., Dingus, T. A. (2008). A method for evaluating avoidance systems using naturalistic driving data. *Accident Analysis and Prevention,* 40, 8-16.

Objective: To develop a method for evaluating the performance of collision avoidance systems (CAS) based on speed and acceleration data for the subject vehicle and a principal other vehicle, and separation distance between the two vehicles.

Methods: Based on ND data from 13 rear-end 60 rear-end near crashes, different algorithms was developed in order to define the latest point in time where a deceleration would have been necessary in order to avoid a collision. The ND data enabled identification of the “observed response point”, i.e., the point in time when the driver initiated an avoidance response, and the speed and acceleration level immediately before that point were inputs to equations to predict position and speed in the case of no avoidance response. Three different alternative decelerations were investigated, and combined with various assumptions of reaction times. The different CAS algorithms were tested in “normal” traffic by applying them to a set of ND data during normal driving, in order to investigate the frequency of false alerts.

Results: With all the tested algorithms, the frequency of false alerts appeared to be unacceptably high. Further developments and applications of the method are discussed, e.g. the possibility to predict the accident-reducing potential of various CASs.

Research question(s) addressed: Assessment of effects of ADAS.

9 Naturalistic driving performance during secondary tasks

Sayer, J. R. Devonshire, J., Flannagan, C., Arbor, A. (2007). Naturalistic driving performance during secondary tasks. In: *Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle*.

Objective: Although a part of a field operational test in which the main aim was to investigate the potential safety impacts of an integrated lane-departure and curve-speed warning system (RDCW), the present paper presents data on secondary driving behaviour in general – i.e., not specifically associated with the RDCW system. Thus, the objective of this study was to investigate frequency of engagement in various secondary behaviours, as well as effect on various driving behaviour measures.

Methods: 36 drivers drove an instrumented RDWC-vehicle for 26 days. Participants were identified as young, middle, or older age, and everyone had been driving for at least two years.

The equipment consisted of a video camera of the driver's face. A representative sample of 18 281 video clips were examined, and 1 440 clips were analysed. Researches coded the video clips for secondary behaviours. In addition, dependent variables were measured, including steering wheel angle, mean and variability of lane position, variability of speed, and mean and variability of throttle position.

Results: The results indicated that secondary behaviours while driving are neither equal in frequency of occurrence nor in effect on driving behaviour performance. Generally, little effect of secondary behaviours on driving performance was found. Of the dependent variables, steering wangle variance seemed to be most affected by secondary tasks. More specifically, use of cellular phone, eating and drinking, and conversations (with passengers) were associated with higher steering angle variance. In addition, some differences in glance behaviour were detected; cell phone use was associated with fewer and shorter glances, whereas eating/drinking was associated with more, but shorter glances.

The study concludes that secondary behaviours have limited effects on continuous driving performance measures.

10 The sleep of commercial vehicle drivers under the 2003 hours-of-service regulations

Hanowski, R. J., Hickman, J., Fumero, M. C., Olson, R. L., Dingus, T. A. (2007). The sleep of commercial vehicle drivers under the 2003 hours-of-service regulations. *Accident Analysis and Prevention*, 39, 1140-1145.

Objectives: In 2003 revised hours of service (HOS) regulations were introduced in the US after research suggested truck drivers were getting less than 6 h a night on average. The revision included (a) a 2 h extension of off-duty time from 8 to 10 h to give more time for restorative sleep; and (b) an extension of maximum driving time in one session from 10 to 11 h.

The questions in this study were:

- How much sleep are the drivers now getting / are drivers getting more sleep under the new HOS regs?
- Is there a relationship between amount of sleep and involvement in critical incidents on the road?

Methods (participants, equipment): 82 drivers from three companies drove along their normal route in a ND study. Since the ND study was also being run as a field operational test of a drowsy driver warning system, the drivers drove primarily at night.

Drivers were assigned one of 38 fitted trucks and drove for up to 16 weeks.

Methods: Sensors were used to monitor driver performance and video to record driver´s face and three views from outside the truck (one forward road, two facing rear along each side of truck). Data collection was triggered by turning of the ignition key.

A driving questionnaire and actigraphy (sleep quality and quantity) data was also collected.

The dataset includes an estimated 1.69 million miles of driving data. Critical incidents were identified using a software program to search the data files for spikes in sensors (e.g. all occurrences of longitudinal accelerations of over plus or minus 0.35 *g*). All possible incidents were then validated using video review.

An event´s validity required the consensus of three researchers. Valid events were categorised as crash, near crash or crash-relevant conflict using operational definitions given in the paper.

Results: The average amount of sleep for 73 drivers was around 6.2 h, indicating an increase in sleep after the HOS revision.

There was no difference in occurrence of critical incidences between the tenth and eleventh hour of driving, indicating that the extension of driving time by the revised HOS has not been detrimental to safety *for these drivers*. (NB This given in associated report).

Analysts judged that for 43 of the 58 critical incidents occurring in the tenth and eleventh hour of driving the subject driver was at-fault. These incidents involved 27 drivers.

For each driver involved in these critical incidents, the driver´s overall mean sleep quantity was compared to the quantity of sleep for the same driver in the 24 h before the critical incident occurred. Where the driver was at-fault, the average sleep before the incident was 5.25 h compared to an overall mean for the same driver of 6.7 h.

Even for those not-at-fault drivers involved in incidents, sleep was less the night before, indicating that fatigue could have played a role in how they responded to the incident.

Implications: The HOS regulations may have increased the time truck drivers spend sleeping.

Fatigue is still implicated as a major factor in critical incident events.

Limitations: The important question “are there less fatigue-related critical incidents occurring after the HOS regulations?” is not addressed.

Sketchy on the maintenance of DAS, how much data was lost and quality control of data used.

Details of the method sketchy because the data is taken from a FOT of a drowsy driver warning system (available in more detail in Hanowski et al., 2008)

Analysis of partial data set. Complete data set analysed in Hanowski et al. (2009).

Based on results from a small number of drivers from only three companies. These companies have their own cultures, norms and procedures that can influence the amount of sleep a driver has. The sort of companies that agree to participate in a study like this may be those companies that are most concerned about safety, driver fatigue and ensuring their drivers get more sleep. It would have been better to sample a larger number of companies.

The drivers do not use their own trucks. Factors such as driver-crafted cabin environments, familiarity with the truck response may have influenced the role of fatigue.

Many miles of data redundant?

How accurate is the automised identification of critical incidents from spikes in sensor recordings? Are any incidents missed? Presumably the method is validated elsewhere?

What about sleep prior to the 24 hour build up? There is evidence elsewhere that sleep patterns in the preceding few days (build up of sleep deficit) is important.

The study does not distinguish between work and non-work days and the influence they may have on the quality of sleep.

Indeed *quality* of sleep and its impact on fatigue is ignored altogether.

No attempt is made to account for driver lifestyle impact on fatigue eg alcohol consumed the night before, food intake at certain times of day etc. Is this really a trade-off that must be made in order to maintain the naturalistic state of the study?

No comment about what the drivers knew about the purpose of the study, though presumably they could guess since they wore activity monitors?

11 A descriptive analysis of light vehicle-heavy vehicle interactions using in situ driving data

Hanowski, R. J., Hickman, J., Wierwille, W. W., Keisler, A. (2007). A descriptive analysis of light vehicle-heavy vehicle interactions using in situ driving data. *Accident Analysis and Prevention*, 39, 169-179.

Objectives: The main objective of this study was to gain a better understanding of incidents between light vehicles and heavy vehicles, as well as shedding light on inconsistencies in the literature concerning light vehicle - heavy vehicle incidents. This was conducted by studying driving behaviour of heavy vehicle drivers before, during and after a critical incident between light vehicles and heavy vehicles. Thus, the incidents are investigated from the heavy vehicle perspective.

Methods: Each of 42 male driver participants drove an instrumented vehicle for two consecutive weeks. The mean age of the drivers were 31, ranging from 19 to 57.

Unobtrusive video camera units were installed in heavy vehicles in order to characterize critical incidents between light vehicles and heavy vehicles, as well as the main contributing factors to these incidents. Video cameras provided almost complete coverage around the vehicle and of the driver's face, accelerometer, steering, directional signals, cab microphone, brakes etc.

Critical incidents were primarily identified by flagging events in the trucks' sensors exceeded a specific value: longitudinal deceleration above 0.5 g, longitudinal acceleration above 0,5 g, absolute lateral acceleration above 0,25 g and longitudinal speed above 32.19 km/h, absolute steering angle rate above 6.28 rad/s and longitudinal speed above 32. 19 km/h, and finally absolute lateral acceleration above 0,5 g. In addition, drivers could flag an incident themselves. Also, analysts' subjective judgements were used to identify critical incidents.

Analyses were conducted by trained data analysts. Valid critical incidents were classified according to a taxonomy structure and Accident Type and Critical Reason (from the Large Truck Crash Causation Study, LTCCS):

- Responsibility
- Incident Type
- Primary Maneuver
- Contributing Factor
- Accident Type
- Critical Reason

Results: 210 critical incidents were recorded, of which 78 percent were initiated by the light vehicle. As for light vehicle initiated incidents, the primary contributing factor was 'aggressive driving', whereas the primary contributing factor for heavy vehicle initiated incidents was 'poor driving skills'.

Limitations: The main limitation of this study is that naturalistic observation only was possible in the heavy vehicles, resulting in incomplete understanding of the light vehicle drivers' behaviour.

12 Extending parental mentoring using an event-triggered video intervention in rural teen drivers

McGehee, D. V., Raby, M, Carney, C. Lee, J. D., Reyes, M. L. (2007). Extending parental mentoring using an event-triggered video intervention in rural teen drivers. *Journal of Safety Research,* 38, 215-227.

Objectives: The main aim of this study was to investigate potential safety effects of giving feedback to teen drivers on their driving by means an event-triggered video device, and subsequent parental feedback. Both immediate and delayed (parental) feedback on teen driving behaviour was given, but there was no opportunity to differentiate between the two types of feedback.

Methods: A quasi-experiment with a before-after design was conducted. The study consisted of three phases over the course of a year; 1) a baseline study (9 weeks) in which participants' driving behaviours were recorded, but did not get any feedback on their driving at all, 2) an intervention phase (9 weeks) in which participants got feedback on their driving in two ways, a) by means of a light signal whenever a safety related incident happened, and b) by means of parental feedback in which parents and teen driver went through the video material together, and 3) second baseline (not finished at the time the paper was written) in which participants get no feedback. The objective of the second baseline is to observe if participants' behaviour will return to first baseline standards.

26 young drivers (16 and 17 year old), twelve males and fourteen females, drove instrumented cars for about a year. They were paid $25 per month.

The event triggered data recorder was a DriveCam device consisting of two video cameras recording forward and interior view, a two-axis accelerometer, a 20-second data buffer, and a wireless transceiver. In addition to recording of the forward roadway and the interior, lateral and longitudinal acceleration, date, and timer are recorded. Moreover, an event is "triggered" when the accelerometer exceeds a threshold (lateral, longitudinal, or shock). A trigger like that causes 20 seconds of recording – 10 seconds before and 10 seconds after the event.

Results: The results from the first baseline phase indicated that the participants in this study could be grouped in two: those who were involved in few safety-related events (low frequency group) (18 drivers) and those who were involved in many safety-related events (high frequency group) (7 drivers). In the intervention phase, the low frequency group more or less maintained their behaviour with regard to safety-related events, whereas there was a large and significant drop in safety-related events for the high frequency group. Also, seat belt use increased from 81.8 percent to 96.9 percent.

Limitations: As this was a quasi-experiment, it cannot be ruled out that changes in driving behaviour are caused by potential confounding variables. Including a control group not receiving the intervention (e.g., feedback), would alleviate this problem.

13 Modeling duration of Lane Changes

Toledo, T., Zohar, D. (2007). Modeling duration fo lance changes. *Transportation Reserach Record*, 1999, 71-78.

Objectives: Previous models of lane changing neglect the detailed modelling of the lane-changing action itself, and model it as an instantaneous event. Studies have found, however, that lane changes may take up to 16 seconds, with a mean duration of about 5 to 6 seconds. The main aim of the present project was to investigate lane change durations of passenger and heavy vehicle cars by using a large set of trajectory data.

Method: The data was gathered by means of high-mounted video cameras on two different days in California. The data include observations on the physical dimensions of all vehicles and the positions and lanes they travel in. Data were collected at three different time periods; off-peak (low traffic densities, high travel speeds), transition (buildup to congestion), and peak period (congested traffic). On the days of data gathering the weather was clear and the road was dry.

No incidents or events were identified during the data gathering periods. A lane change initiation and completion was defined as the time when the lateral movement of the subject vehicle began and ended. The lane change duration is the time lapse between its initiation and completion.

Variables that may explain lane-change durations were generated. These include: traffic characteristics, characteristics and state of the subject vehicles, and relations to other vehicles around the subject vehicle.

Results: 1790 successful lane changes were identified, of which 112 (6.3 %) were done by heavy vehicles. 70.3 percent of all lane changes were to the left.

As for passenger cars, the results showed that lane changes to the left had a longer duration than to the right, with a difference of about 0.3 seconds. This is explained by risk aversion – changing lanes to the left most often involves changing to a faster lane, which is more risky, and consequently drivers are more cautious and take longer time. Risk aversion is assumed to be the explanation for several of the findings concerning passenger car lane changes. Mean duration of a lane change was 4.6 seconds, ranging from 1.0 to 13.3. Lane change durations were affected by traffic conditions, direction of the change and other vehicles around the subject vehicle.

The mean duration of lane changes for heavy vehicles were shorter than for passenger cars, which is explained by the fact that heavy vehicle drivers are professional drivers. Moreover, heavy vehicles had a longer mean duration when changing to the left compared to the right. This is explained by the good field of view heavy vehicles have to their left compared to the right.

In general, the models tested in the paper suggest that lane changes for passenger cars and heavy vehicles differ significantly. However, for both types of cars lane-change durations are longer when the maneuver is riskier or when the task is complicated by other vehicles.

14 Long-term effects of training in economical driving: Fuel consumption, accidents, driver acceleration behaviour and technical feedback

af Wåhlberg, A.E. (2007). Long term effects of training in economical driving: Fuel consumption, accidents, driver acceleration behaviour and technical feedback. *International Journal of Industrial Ergonomics,* 37, 333-343.

Objectives: The objective of this study was to investigate long term-effects of an eco-driving course given to bus drivers. More specifically, the following research objectives were addressed: 1) study the effects of training in fuel-efficient driving on three variables; fuel consumption, accident rates and acceleration behaviour, and 2) study the effect of technical feedback on the same three parameters.

Methods: A quasi-experiment was conducted with naturalistic data gathered in a fleet of buses in Sweden. The design included two manipulations at different times (Training in heavy ecodriving and technical feedback in buses), before and after measurement, experimental and control group, and three dependent variables (fuel consumption, accident rates and acceleration behaviour).

Measures of fuel consumption and accident data were available from the bus company's records.

Subjects in the study were drivers in the bus company (N=350-400 at any one time). The experimental and control group were similar on most variables, except that of 'hours worked'.

Results: All in all, the results indicated little or no long-term effects of driver training on the measured variables. As for fuelling, a reduction in fuel consumption of about two percent (mean over 12 months after training) was found. No effects were found for accidents. In the second phase of the experiment, the effect of technical feedback during driving was investigated, and the results showed a further reduction of about two percent.

Limitations: various confounding variables and potential error sources in the data set is discussed.

15 Association of intersection approach speed with driver characteristics, vehicle type and traffic conditions comparing urban and suburban areas

Liu, B.S. (2007). Association of intersection approach speed with driver characteristics, vehicle type and traffic conditions comparing urban and suburban areas. *Accident Analysis and Prevention,* 39,216-223.

Objectives: The main objective of this study was to use a site based observation method to study drivers' speed when approaching an intersection. More specifically, speeding violations when approaching an intersection was studied in relation to age, gender, vehicle type, traffic light status, site (urban vs suburban), rush-hour-status, passenger status, and weather.

Methods: Observations were made at one urban and one suburban intersection. A speed-measurement device (a laser speed gun) and tripod-mounted cameras were used to record vehicle speed and driving behaviour. Speeds of 1538 vehicles were recorded. As this was a site based observation study, all drivers were unaware of being observed. Nevertheless, using the video data, driver characteristics such as estimated age, gender, presence/absence of passengers in the vehicle, and type of vehicle were recorded.

For each of the locations, observations were conducted in rush and non-rush hours. Also, the weather for the observations was stratified into sunny and cloudy days.

Results: Multiple regression analyses and binary logistic regression analyses were used to analyse the data. The results indicated that the major contributing factors for approaching speed were site, rush-hour-status, traffic light condition, vehicle type and driver gender. Moreover, the binary logistic regression indicated significant site and rush-hour effects on speeding, with the risk of violation of speeding in the suburbs nearly six-fold that in urban areas. Also, the relative risk of speeding during non-rush hours is three times higher than that for rush-hour. Finally, male drivers under 55 years of age had the greatest speeding propensity.

16 Car-bicycle conflict in the junction between Sørkedalsveien and Morgendalsvegen

Phillips, R., Bjørnskau, T., Hagman, R. (2007). *Samspill i Sørkedalsveien – 6 år etter.* Institute of Transport Economics, Oslo.

Objective: The influence that cycle paths have on cyclist accident numbers is not clear.

There are many dimensions along which cycle path contexts can vary, including local population, relative traffic mode volumes, degree of path separation and the number of junctions along the path. The differing effects of cycle paths are probably caused by unique combinations of such dimensions in different contexts.

Naturalistic studies on the effects of introducing a cycle path at a road junction are difficult to find. It can therefore be argued that little is known about what really goes on when a junction environment is changed in this way.

This study aims to use NO to explore an important addition to the list of dimensions that can be used to predict cycle path effects, that of learning and adaptation by those road users regularly encountering the cycle path.

Method: A total of 57 hours of video registrations were made of interactions between cars and bicycles at a Norwegian road-cycle path intersection, 2, 50 and 120 months following junction alteration.

The alteration was the introduction of a cycle path across a T-junction leading from a housing estate to a main commuter road. Many of the road users using the junction could be considered as routine users.

The interaction events were defined by a video analyst as either yielding (slow braking and/or turning to avoid other road user) or conflict (harsh braking and/or turning to avoid other) events.

Attempts were made to assess inter-rater reliability by having two video analysts assess a part of the data in isolation, and then comparing classifications. Reliability was assessed as 86 per cent.

Results: A significant decrease in overall conflict levels was found four years after path introduction (from 3.0 to 0.7 per cent of interactions resulted in conflict), and a subsequent decrease between four and ten years (from 0.7 to 0.4 per cent) was close to significance.

The decrease in conflict was mirrored by an increase in the number of those give-way events not resulting in conflict.

The give-way and conflict situations registered were classified according to eight possible intersection scenarios, and compared over time to the yielding behaviours of drivers and cyclists in each scenario. Those scenarios in which no conflicts occurred in over 28 hours of registrations ten years following path introduction were the very same scenarios in which significant changes in driver yielding behaviour was detected between four and ten years following path introduction.

Implications: Together these results have important implications both for cycle path evaluations and the modelling of road user behaviour at junctions.

The results might imply that learning occurs over time after road junctions are altered.

The method allows both the change in behaviour and critical incidents to be recorded, allowing links to be made between the two.

Changes were consistent with a theory of learning according to (a) potential danger in a particular junction situation and (b) Level of cognitive distractors in that situation.

Limitations: An assumption was made that most of the road users were routine users but there was no evidence of this.

Data collection was limited by resource. A longer data collection at each time points and data collection at more time points would have led to greater statistical certainty about the change in conflict levels and the behavioural causes of that change.

Study of a control junction, in which no alterations were made, would have been clearly preferable.

17 The 100-Car Naturalistic Driving Study: A descriptive analysis of light vehicle-heavy vehicle interactions from the perspective of the light vehicle driver’s perspective

Hanowski, R. J., Olson, R. L., Hickman, J., Dingus, T. A. (2006). *The 100-car naturalistic driving study: A descriptive analysis of light vehicle- heavy vehicle interactions from the light vehicle driver’s perspective.* Report No. FMCSA-RRR-06-004. National Highway Traffic Safety Administration (NHTSA), Washington D.C.

Objectives: The main objective of this study was to investigate light vehicle-heavy vehicle interactions from the perspective of the light vehicle driver. More specifically, the following goals were addressed:

- Gain a better understanding of LV-HV interactions on U.S. roadways
- Develop the classification scheme and contributing factor list for LV-HV interactions (Hanowski et al 2004?)
- Compare the data from this study with data obtained for LV-HV interactions from the heavy vehicle driver's perspective (Hanowski et al 2004)
- Provide background information in order to develop countermeasures for LV-HV interactions

Methods: see section on general information about the 100-Car Naturalistic Study for information about sample, instrumented vehicles etc.

Interactions between light vehicles and heavy vehicles were defined as "critical incident", i.e., as unexpected events resulting in a close call or requiring an evasive maneuver to avoid the crash.

Results: 9125 critical incidents were identified in the 100-car naturalistic survey. Of these, only 247 (2.7 %) were LV-HV interactions.

Excluding the incidents in which no driver could be identified as the responsible part in the incident, 64 percent of the incidents were found to have been the fault of the light vehicle driver, whereas the heavy vehicle drivers were at fault in 36 percent. The finding that the light vehicle drivers were responsible in a substantial proportion of the incidents supports previous findings.

Moreover, the different incident types were different depending on whether the light vehicle or the heavy vehicle driver was responsible. The most frequent incident types when light vehicle drivers were responsible were: late braking for stopped/stopping traffic (41.3 %), lance change without sufficient gap (21.7%), and aborted lane change (8 %). The most frequent incident types for heavy vehicle at-fault drivers were: lane change without sufficient gap (26.6 %), lateral deviation of through vehicle (21.5 %), and left turn without clearance (13.9 %).

There were also differences between LV drivers at-fault and HV drivers at-fault when it comes to primary maneuvers. The primary maneuvers for light vehicle drivers at-fault were braking (32.6%), stopped (21.7 %) and changing lanes (16.7%), whereas the most frequent primary maneuvers for heavy vehicle drivers were changing lanes (32.9%), crosses over lane line (20.3%) and left turn (15.2 %). The two most frequent primary maneuvers of light vehicle drivers were connected to difficulties of decelerating or stopping on part of the LV driver. The two most frequent primary maneuvers of heavy vehicle drivers were connected with difficulties of changing or crossing the lane line.

As for the contributing factors, the most frequent factors for incidents where light vehicle drivers were at-fault were driving technique (70.3%), distracted (22.5%), and aggressive driving (22.5%). For heavy vehicle drivers at-fault, the most frequent contributing factors were unknown (68.4%), driving techniques (15.2%), and distracted (11.4%). The large number of unknown factors on part of the heavy vehicle drivers is due to the fact that this study was conducted from the light vehicle driver perspective.

Accident types[8] were also analysed separately for light-vehicle drivers at-fault and heavy vehicle drivers at fault. The results indicated that the accident types for light vehicle drivers at fault reflected the primary manevuers analyses and were associated with stopped or decelerating. The accident types in which the heavy vehicle drivers were at-fault, on the other hand, reflected their primary manevuers: changing lanes and crossing the lane line.

In addition to the results specific for the 100-car data only, comparisons with previous results were also made. One difference that was found was related to the contributing factors when light vehicle drivers were at-fault: In the present study, 22. 5 percent of the light vehicle incidents had ‘aggressive driving’ as the main contributing factor, compared to only 4.3 percent and 31.1 percent in previous studies. However, these were based on crash databases. It is believed that a naturalistic study provides better insight into the interaction between light and heavy vehicles.

There were also several inconsistencies in results between previous naturalistic driving studies and the 100-car data. Nevertheless, all these have found that light vehicle drivers are more likely to be responsible for the light vehicle-heavy vehicle incidents than heavy vehicle drivers.

18 The 100-Car Naturalistic Driving Study: Phase II – results of the 100-car filed experiment

Dingus, T.A, Klauer, S.G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, et al. (2006). *The 100-car naturalistic driving study, phase II – results of the 100-car field experiment.* Report no. DOT HS 810 593, National Highway Traffic Safety Administration (NHTSA), Washington, D.C.

Objectives: This report presents results from phase II of the 100-car study, i.e., main results from the field trials. More specifically, the goals of this particular part of the study were:

- Characterisation of crashes, near-crashes, and incidents for the 100-car study
- Quantification of near-crashes
- Characterisation of driver inattention
- Driver behaviour over time
- Rear-end conflict causal factors and dynamic conditions
- Lane change causal factors and dynamic conditions
- Inattention for rear-end lead-vehicle scenarios
- Characterise the rear-end scenarios in relation to Heinrich’s Triangle

[8] Note that there were no actual accidents between light vehicles and heavy vehicles in the 100-car data set, and Accident type is identified for the critical incidents instead.

- Evaluate performance of hardware, sensors and the data collections system

Method: See section on general information about the 100-car study

Results: There were 82 crashes recorded during the study period. However, data were only eligible for 69 of these crashes. In addition, 761 near-crashes and 8 295 incidents were recorded. Approximately 7 percent of drivers were involved in 3 or more accidents, 7 percent were involved in 2 accidents, and 22 percent in 1 accident.

Attempts were made at quantitatively identifying near-crash events, i.e., to determine quantitative guidelines to decide when an event was a near-crash (i.e., longitudinal deceleration of at least 0.5 *g*). Even though the analyses were somewhat successful in developing a near-crash data-based trigger for a large-scale data collection effort, on a general note the data showed that development of purely quantitative near-crash criteria is not currently feasible for most cases. This is most probably due to the fact that the kinematic signatures associated with near-crash events are virtually identical to many common driving situations that are not indicative of crash risk. Consequently, identification of near-crashes should be verified by use of video-data.

Results regarding driver inattention and distraction are presented in details below (Klauer, Dingus et al. 2006; Klauer, Sudweeks et al. 2006).

As for investigating driver behaviour over time, three issues were explored: 1) driver behaviour in a newly instrumented leased vehicle in the first weeks compared to the last weeks, 2) driver behaviour in the first few hours of driving, and 3) driver behaviour for the same driver in leased vehicle compared to the behaviour of the same driver in private vehicle. As for driver behaviour over a year (issue 1) the underlying objective was to study any adaptation to the instrumented vehicles over the course of the study. There were no appreciable changes in the number of events over the course of the study, but there was a consistent tendency showing higher risk for events for leased vehicle drivers compared to private vehicle drivers. One explanation is that drivers of leased vehicles are more willing to take risks leading to near-crashes and incidents since they would not be responsible for insurance or repairs.

Moreover, it was hypothesised that drivers would be more careful in the first few hours of driving an instrumented car, but would adapt to the car and situation after a period (issue 2). The results indicated that drivers were very careful during the first hour with a newly instrumented vehicle. However, this ‘careful-effect’ which probably is due to the fact that the participants were thinking about being observed (Hawthorne effect) wore off after the first hour. Importantly, the difference between leased and private vehicles was evident here as well with leased vehicles experiencing a greater mean number of events for nearly every time period studies. This was true also when controlling for age.

Finally, differences between driving a leased vehicle and private vehicles were investigated also by comparing drivers driving a leased vehicle for four weeks with the same drivers driving their private vehicle for four weeks (issue

3). The results supported the previous findings that leased vehicles drivers had more events than private vehicle drivers.

As for rear-end conflict causal factors and dynamic conditions, analyses were made in which the subject vehicle was both follow-vehicle and lead-vehicle (this was possible as subject vehicles were instrumented with camera views of both the forward and backward roads). The most common scenario was when the lead vehicle was decelerating (both when the lead vehicle was the subject vehicle or not), followed by lead vehicle stopped for more than two seconds and less than two seconds. 18-20 year-olds had the highest rate of incidents per mile in the lead-vehicle age data. Moreover, 'traffic density' was the most important contributing factor for all lead-vehicle scenarios, followed by 'relation to junction', 'traffic control', 'light' and 'weather'.

Rear-end conflicts were also investigated in relation to lane changes. No crashes occurred when there was a lane change in front of the subject vehicle, nor when there was a lance change behind the subject vehicle. However, several near-crashes and incidents occurred when there was a cut-in to the lane in front of the subject vehicle, and also when the subject vehicle changed lane behind a lead vehicle. There were more near-crashes and incidents in the former of these scenarios than in the latter. Thus, fewer events occurred when the subject vehicle was the cut-in vehicle, probably because the drivers were more alert an attentive when they were actively performing the lane change maneuver.

Moreover, rear end lead-vehicle scenarios were investigated in relation to inattention and distraction. In these data, 93 percent of all lead-vehicle crashes (14 of 15) involved inattention to the forward roadway as a contributing factor. Inattention was a contributing factor to the majority of near-crashes, and in one-third of the incidents. The results indicate a strong correlation between inattention and severity for lead-vehicle rear end events. Wireless devices were the most frequent contributing factor for lead-vehicle events and this was also true for near-crashes.

As near-crashes and incidents are far more frequent than actual crashes, the potential for using near-crashes and/or critical incidents as surrogate measures for crashes were investigated. This was done by characterising the rear-end scenarios in relation to Heinrich's triangle. For driving, the theory of Heinrich's triangle says that a crash most often is caused by a series of events, including 1) a precipitating event, 2) contributing factors, and 3) the absence of a successful evasive maneuver. Thus, when a precipitating event occurs, the presence of contributing factors determine whether it is responded to early (incident), late (near-crash) or ineffectively (crash). Analyses were made in order to estimate the rates of the differing severities of lead-vehicle conflicts and associated 95 percent confidence limits modelled as a Poisson distribution for each category. The results indicate that measuring less severe conflict surrogates can provide reasonable estimates of crash risk if a larger-scale study is conducted.

19 The impact of driver inattention on near-crash/crash risk: An analysis using the 100-car naturalistic driving study data

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.* Report No: DOT HS 810 594. National Highway Traffic Safety Administration (NHTSA), Washington D.C.

Objectives: The research objectives of this part of the 100-Car Naturalistic survey were all related to distraction and inattention. More specifically, the following objectives were addresses:

- What is the prevalence as well as the types of driver inattention in which drivers engage during their daily driving? What is the relative near-crash/crash risk of driving while engaging in an inattentive task? Is the relative near-crash/crash risk different for different types of secondary tasks?
- What are the environmental conditions associated with driver choice of engagement in secondary tasks or driving while drowsy? What are the relative risks of a crash or near-crash when engaging in driving inattention while encountering these environmental conditions?
- Determine the differences in demographic data, test battery results, and performance-based measures between inattentive and attentive drivers. How might knowledge be used to mitigate the potential negative consequences of inattentive driving behaviours? Could this information be used to improve driver education courses or traffic schools?
- What is the relationship between measures obtained from pre-test batteries and the frequency of engagement in distracting behaviours while driving? Does there appear to be any correlation between willingness to engage in distracting behaviours and measures obtained from pre-test batteries?
- What is the relative near-crash/crash risk of eyes off the forward roadway? Do eyes off the forward roadway significantly affect safety and/or driving performance?
- Are there differences in driving performance for drivers who are engaging in a distraction task versus those drivers who are attending to driving? Are some of the safety surrogate measures more sensitive to driving performance differences when driving distracted versus other safety surrogate measures?

Measures: In order to investigate these research objectives, various measures were used from the 100-car study: data on events, i.e., crashes, near-crashes and other critical incidents were used from the event base, data on prevalence of driving while distracted, including eye-glances, was extracted from a baseline data base. In addition, data from various self-report questionnaires that drivers answered before or after the period of driving in an instrumented car were used.

Results: The results showed that driving while drowsy was associated with an increase in near-crash/crash risk of about four to six times, whereas conducting complex secondary tasks increased risk by three times. Moderate complex tasks were associated with an increase in risk by two times. Driving-related inattention to the forward road was, on the other hand, related to a decrease in risk compared to normal, baseline driving. As for population attributable risks, the results showed that driving while drowsy contributed to 22 to 24 percent of crashes and near-crashes, whereas complex secondary tasks contributed to about 22 percent of all crashes and near-crashes. Also, a strong correlation was found between inattention related near-crashes/crashes and engaging in inattention-related activities under baseline driving.

Moreover, analyses of eye-glance behaviours indicated that having the eyes off the road for more than 2 seconds significantly increased near-crash/crash risk, whereas the same was not true for eye-glance off the road for less than 2 seconds.

As for the prevalence of driving inattention, the results showed that 54 percent of baseline epochs drivers were engaged in secondary tasks, while driving related inattention was present in 44 percent of epochs. Drowsiness was presents in 4 percent of epochs, whereas non-specific eye-glances were present in 2 percent of epochs.

In addition to distinguishing between degree of complexity for the various distractions, relative risks were also estimated for specific distractions. For instance, dialling a hand-held phone/device was associated with an increase in near-crash/crash risk, whereas talking on a hand-held phone did not increase risk significantly. However, estimating the population attributable risks, the results showed that talking on a hand-held phone and dialling contributed to the same about of near-crashes and crashed, as there is a higher prevalence of talking than dialling when driving.

Analyses were also made in order to address the question of driver inattention under different environmental conditions. As for drowsiness, the results showed that a higher percentage of drowsiness-related baseline epochs were present during free-flow traffic on divided roadways, and areas where roadway junctions were absent. As for secondary tasks, all environmental conditions resulted in increased risk when engaging in complex tasks, whereas as moderate secondary tasks rarely resulted in significant risk ratios over 1.

Finally, the results showed that drivers who had high involvement in inattention-related crashes were younger and had less driving experience than drivers with low inattention-related crashes. Also, high-involvement drivers reported more traffic violations and involvement in accidents prior to the actual study. In addition they were more often drowsy and were different on various personality measures than the low-involvement drivers.

Limitations: The 100-car naturalistic study was only conducted with commuter participants in Northern Virigina/Washington D.C. area and one should be cautious in generalising the results. Also, crash risks are not estimated for actual crashes only, but for near-crashes and crashes. This is because there were few actual crashes, and more observations were needed. The kinematic data for crashes and near-crashes were similar, indicating that near-crashes can be used as a proxy for actual crashes. Nevertheless, the two kinds of events obviously differ, which need to be kept in mind when interpreting the results.

20 How risky is it? An assessment of the relative risk of engaging in potentially unsafe driving behaviors

Klauer, D. G., Sudweeks, J. D., Hickman, J. S., Neale, V. L., (2006). *How risky is it? An assessment of the relative risk of engaging in potentially unsafe driving behaviors.* Prepared for: AAA Foundation for Traffic Safety, Washington, D. C.

The 100-car naturalistic study data set was also used to measure relative risks of other potentially unsafe driving behaviour, which is reported in the report by Klauer et al. (2006). The main objectives of this study was to investigate relative risks associated with a) excessive speed, b) safety belt use, c) driver distraction/inattention, and d) driver drowsiness.

Methods: see section on the 100-Car Naturalistic Survey, and Klauer, Dingus et al. (2006).

Results: The results indicated that the following driving behaviours were associated with an increased risk of involvement in a crash or near-crash: 1) driving at inappropriate speed (OR=2.9), 2) driving while drowsy (OR=2.9), 3) having the eyes off the forward road for more than 2 seconds (OR=1.9), and 4) exhibiting aggressive driving behaviours (OR=2.1).

As for use of seat-belt, the results show that high-risk drivers (those with the highest rate of crashes, near-crashes and incidents per mile driven) were less likely to wear a safety belt than low-risk drivers. Moreover, high-risk drivers were more likely to drive while drowsy than low-risk drivers, and the average rate of crashes, near-crashes and incidents among high-risk drivers were over 100 times that of low-risk drivers.

Limitations: see Klauer, Dingus et al. (2006).

21 The development of a naturalistic data collection system to perform critical incident analysis: An investigation of safety and fatigue issues in long-haul trucking

Dingus, T. A., Neale, V. L., Klauer, S.G., Peterson, A. D., Carroll, R. J. (2006). 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 and Prevention*, 38, 1127-1136.

Objectives: Despite much evidence that drowsy driving is a problem, we still do not know how those factors causing fatigue (circadian effects, sleep quality) are related to other crash contributing factors (traffic, road type etc.).

This is in part due to a shortcoming in the quality of data available in large crash databases. Although attempts have been made to address this using surrogate approaches (simulators, instrumented vehicles), they do not directly measure safety in terms of crash frequency or severity.

A hybrid approach is therefore proposed in which crash data is collected on a smaller scale than that required for true epidemiological study, but on a large enough scale for critical incident or near miss analysis. Such an incident-based ND approach is the most valid safety surrogate, according to the authors.

Further, this particular study improves on a similar previous one by the same group (see Hanowski et al., 2000) by allowing enough storage for continuous data collection, providing sufficient resource for reduction and analysis of continuous data, and therefore being able to analyse more incidents.

Methods: There were 56 participants from four long-haul trucking companies, and each was paid $630 for participation.

26 of the participants drove in 13 teams of two.

They drove test-tractors from the research institute but pulled their normal cargo on their normal routes.

They were given detailed training on tasks, procedures and orientation of the vehicle. This lasted 60-90 min.

The data acquisition system (DAS) in the truck started to collect data 1.5 min before and 0.5 min after one of several types of trigger events. This technique enabled continous data collection analysis afterwards.

The triggers were fast steering wheel turning; high lateral or longitudinal acceleration; depression of a critical incident button by the driver; lane boundary exceedence; short time-to-collision with a lead vehicle; Perclos monitor showing eyes closed for 80% of time or more; randomly prompted Karolinska sleepiness scale (KSS) rating by driver; no response by driver to KSS trigger. There was also a timed trigger for baseline collection.

The only DAS devices visible to the driver were the Perclos monitor and KSS and critical incident pushbuttons.

The drivers were asked to don a sleep-monitoring device before sleeping and rate subjective ratings of sleepiness when they woke up.

The cameras were located to observe the driver face, road ahead, and view to the rear along each side of the truck. These were arranged in quadrants on a single screen for analysis. Codes for trigger types showed up on the continuous video when they were activated.

Five analysts were trained and all had experience of this work. They were trained in three sessions to synchronise ratings with those of a more experienced analyst. Their work was spot checked and weekly meetings held to discuss any issues.

Triggered events were analysed in the following way.

They were classified as critical or not using operationalised definitions.

The severity of the trigger was further categorised as ´driver error without hazard present´, ´driver error with hazard present´, ´near collision´or ´collision´.

Each event was given one of eight trigger descriptions e.g. obstacle present.

Each event was assigned a value one of nine categorical variables describing road condition. Each of these categories had up to ten values.

For each event the analysts also assigned to the driver scores on the observer ratings of drowsiness (ORD) scale.

(It is not clear whether all triggered events, even invalid events, are classified in this way, presumably just critical incidents are classified?)

Thus the variables collected included all those recorded ´live´ by the DAS and by the driver, and those recorded afterwards by the analysts.

Results: One of the main results of this paper was the method itself. Understandably, given the amount of data (400,000 km driven), only a limited analysis of the data collected is presented, to show that the method can work.

The analysis is based on data from 13 of the single drivers and 7 of the teams of two drivers (27 drivers in total). Efforts are made to ensure the duration of data collected is accounted for in analyses.

The analyses show that single drivers had more critical incidents than team drivers, and that this difference could not be accounted for by age, experience or hours driven alone.

The chances for a critical incident were highest in daylight hours between 11.00 and 12.00 and 15.00 and 18.00 (latter could be circadian dip).

Whereas team drivers are rated as ”very drowsy” only in critical incidents occurring at night, single drivers are rated as very drowsy mostly in the afternoon, but also in the morning, evening and night.

Analysis of severity of critical incidents indicates that single drivers drive more aggressively in general.

Implications: Clear support for fatigue as an issue in long-haul safety.

The highly structured analysis of triggered events results in a set of data that can be analysed for many different purposes (fatigue, attention, age, hours of service regulation).

The method provides advances in efficiency and structure of data collection and should be considered for use in future studies in which it is not necessary to collect continuous data.

The difference for team and single drivers implies that organisational factors are important and may not be accounted for enough in other studies of driver fatigue.

What does the high rate of incidents in daylight hours say about the link between fatigue and critical incidents? Is it just the greater volume of traffic that causes this?

Limitations: The drivers use test-trucks. This raises questions about familiarity, and makes difficult vehicle-driver interactions as factors in fatigue.

During the study drivers are prompted for KSS ratings. This is invasive and informs the drivers what the study is about. Is the study therefore naturalistic?

The number of drivers is still small in relation to the claims made by the author in the introduction. A larger scale study is desirable, but when does even this more efficient method become impracticable in term of the number of analyst hours needed?

Organizational factors particular to those few truck companies involved are not considered.

Concludes that the difference in the number of incidents between single and team drivers is because drivers like to give their partners a smooth ride so they can sleep better (based on focus group findings). What about that they can just swap when fatigued?

22 Evaluating the safety implications and benefits of an in-vehicle data recorder to young drivers

Lotan, T., Toledo, T. (2005). Evaluating the safety implications and benefits of an in-vehicle data recorder to young drivers. In: *The third international driving symposium on human factors in driver assessment, training and vehicle design, TRB*, Rockport, Maine.

Objectives: As part of an evaluation of the program Green Light for Life which is aimed at improving the quality of the accompanied driving period, in-vehicle data recorders (IVDR) were installed in 120 vehicles. In the present study, however, only preliminary results from 4 young drivers and their parents are reported.

The experiment that is outlined in the present study is meant to test the impact of a) participation in the Green Light for Life program and b) the type of feedback drivers receive from the system. More specifically, the following issues will be addressed:

- Characterisation of the driving profiles of young drivers and their families during the accompanied driving period and thereafter
- Continuous monitoring of young drivers
- Monitoring the transition from the accompanied period to the independent period
- Impact of various feedback mechanisms on the performance of both young drivers and their parents

Methods: The IVDR is an on-board device that record information about the movement, control and performance of the vehicle. In order to monitor and analyse the data gathered by means of the IVDR, a system called DriveDiagnostics is used. The DriveDiagnostic system has a four level framework; 1) measurements (speed, acceleration), 2) inference (maneuver detection), 3) analysis – over time (driver, trip level, fuel consumption, accident risk), 4) reporting (real time or off line). Based on their driving performance, drivers are designated as safe, unsafe or dangerous drivers. Feedback on their behaviour can either be in real time by means of an sms, or off-line in a DiverDiagnostic report generator. Note that this system is designed to measure driver behaviour as such, not necessarily connected to crashes or incidents.

Results: The results presented here are based on the observations of 2488 trips made by four pairs of parents and young drivers. Young drivers generated 34 percent more events per hour compared to their parents. Moreover, young drivers generated more turn-handling events indicating unsmooth turns, than the parents. They also generated 24 percent higher rates of lane-handling events. However, young drivers generated lower rates of braking and acceleration events than parents.

23 Driver distraction: A naturalistic observation of secondary behaviors with the use of driver assistance systems

Sayer, J. R., Mefford, M. L., Shirkey, K., Lantz, J. Arbor, A. (2005). Driver distraction: A naturalistic observation of secondary behaviors with the use of driver assistance systems. In: *Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*.

It has been proposed that engagement in secondary – often distracting – behaviours may increase as a consequence of in-vehicle support systems designed to avoid collisions and to reduce the work load of drivers, such as forward collision warnings (FCW) and variants of cruise control (CCC or ACC). The main aim of the reported study was to investigate actual involvement in secondary behaviours among drivers driving vehicles with and without such support systems. This was sought investigated by means of naturalistic driving data as part of a field operational test (the Automotive Collision Avoidance System Field Operational Test).

Methods: A random sample of 66 drivers in southeastern Michigan participated in the study. The sample was balanced with respect to gender, and participants were between 20 and 70 years of age. Each participant drove an instrumented vehicle for approximately four weeks. The first week was a "baseline condition" in which none of the support systems were in function. After the baseline condition, the Automotive Collision Avoidance System automatically switched on.

In order to gather data about the exposure to various secondary behaviours in the baseline and treatment conditions, the system was programmed to capture four-second-long video clips of the driver's face. Images were also captured for the forward scene. Subsequently, a random sample of 5 percent of the exposure clips was analysed, resulting in a sample of 890 such video clips. Trained analysts watched the videos and entered data into a secondary behaviour form. Importantly, though, only secondary behaviours that were possible to identify from the video of the face of the drivers were included.

Results: The results indicated that drivers were no more likely to engage in secondary behaviours when driving with ACC and FCW in comparison to manual control. This was true for all secondary behaviours except conversing with passengers, in which there was an increase when ACC and FCW were active. This is, however, interpreted as drivers explaining the systems to the passengers.

Also, secondary behaviours were observed approximately 19 percent of the time when drivers were driving at speeds greater than 25 mph (in all conditions).

Limitations: Various limitations are present in this study. First, the baseline week only consists of one week in the beginning of the test period. Participant behaviour may have been influenced by the fact that they were observed, and this would probably show the strongest effect in the beginning of the period. However, if participants' behaviour was influenced, it is reasonable to assume that they would perform less secondary behaviour in this period, strengthening the results that engagement in secondary behaviours does not increase when supported by FCW or ACC. Second, from the paper it looks like ACC and FCW were introduced at the same time. Thus it is not possible to investigate potential differential effects of the two support systems.

24 Drivers exposure to distractions in their natural driving environment

Stutts, J., Feaganes, J., Reinfurt, D., Rodgman, E., Hamlett, C. Kenneth, G., Loren, S. (2005). Driver's exposure to distractions in their natural driving environment. *Accident Analysis and Prevention,* 37, 1093-1101.

Objectives: The main objective of this study was to investigate exposure to, i.e., occurrence, of various driving distractions, and these distractions effect on driving. More specifically, the following research questions were addressed:

- How often do drivers engage in distracting behaviours?
- Are there age and sex differences in the occurrences of driver distractions?
- How do contextual variables such as vehicle movement affect driver distractions?
- What are some of the consequences of distraction on driving performance?

Methods: 70 drivers drove their own cars instrumented with video-cameras for one week. Drivers were balanced with regard to gender, and equally distributed among the following age groups: 18-29, 30-39, 40-49, 50-59, 60 +. All participants drove at least 6 hours per week. They were compensated $100.

The vehicles were equipped with a video-camera device containing a microphone and three small cameras catching the driver's face, a broad view of the vehicle inside, and the forward road.

A taxonomy for driver distractions developed from a Crash Database System were used to categorise the various distractions. Driving behaviour performance were measured as 1) whether one hand, two hands, or neither hands was on the steering wheel, 2) whether the driver's eyes were directed outside or inside the vehicle, and 3) whether the vehicle was swerving or wandering within the travel lane, crossing into another travel lane, or stopping from sudden braking.

Due to heavy time requirements in the data analysis process, only 3 hours of total data per participant were coded. These 3 hours were evenly distributed across the total recorded time per participant in one-half hour blocks.

Results: Altogether 14.5 percent of the total time the vehicles were moving, drivers were engaged in one or more distracting activities. Of the total time the vehicles were moving, conversing was observed in 15.3 percent, followed by preparing to eat/drink (3.16 %), smoking (1.55 %), eating/drinking (1.45 %), and using a cell phone (1.3 %).

Females were more likely than men to groom themselves while driving, and to attend to things outside the vehicle. Few differences were found between age groups.

Fairly consistent, though insignificant, trends showed higher levels of no hands on the steering wheel, eyes directed inside the vehicles and higher rates of adverse vehicle events associated with each of the identified driving distractions.

Limitations: In the present study, only frequency of occurrence of the various distraction factors could be identified. In order to fully understand the effects of various distraction factors, level of intensity should be measured in some way. Also, the authors point to problems with objectively defining all distraction categories and context and outcome variables. As for outcome (driving performance) variables, these have not been directly linked to crash risk. Observing more drivers over a longer time period could provide data about actual crashes and near-crashes, alleviating this problem (as has been done in the 100-Car Naturalistic study). Finally, cognitive distractions could not be identified in the present study.

25 Driver distraction in long-haul truck drivers

Hanowski, R. J., Perez, M. A., Dingus, T. A. (2005). Driver distraction in long-haul truck drivers. *Transportation Research Part F. Traffic Psychology and Behaviour*, 8, 441-458.

Objectives: Outlining the drawbacks of experimental and epidemiological research on driving distractions and crashes, this study aims at using naturalistic driving observation as a method to study driver distraction as a contributing factor to critical incidents among truck drivers. More specifically, the objectives of this study were to provide information concerning various distracters including durations and frequencies of these distracters, and then estimate relative risks associated with the distracters. Also, potential relationships between frequency of distraction incidents and driver factors were investigated.

Methods: 42 long-haul truck drivers drove one of two instrumented cars, either alone (single driver) or with another truck driver (team drivers). Data from approximately 140 000 miles were collected. There were 28 males and 5 females, and the age of the drivers ranged from 28 to 63, with a mean age of 42.

The data gathering equipment consisted of camera-devices capturing four views including the driver’s face, a device to measure driving performance information including steering, lane departure, and braking as well as various sleep related measures not relevant for the present study.

Analyses of various distracters were only made in relation to critical incidents, i.e., crashes, near-crashes, and crash-relevant conflicts. All critical incidents were analysed and assigned a primary cause; judgment error, other vehicle, or driver distraction.

Results: 2737 critical incidents were recorded, and distraction was designated as the primary cause for 178 (7 percent) of these incidents. No crashes were recorded, one conflict was a near-crash and the rest were crash-relevant conflicts. ‘Judgment error’ was the most frequent cause (77 percent), whereas ‘other vehicle’ was the primary cause in 9 percent of the accidents.

Two drivers accounted for 43 (24 %) of the distraction related incidents and single drivers accounted for 115 of the 178 distraction incidents. No gender or age effect was observed.

Moreover, results from cluster analyses indicated that the frequency and duration of a task, together with the visual demand with performing the task, contributed in combination to the prevalence of critical incidents. Visually demanding tasks were found to carry the highest degree of risk, relative to other categories of tasks.

Limitations: In this study, exposure to the various distraction tasks were not measured as how often the drivers were engaged in the distraction in question while driving, but the frequency of engaging in the distraction related to a critical incidents. Thus, it is not possible from these data to separate out the effects of task frequency, limiting the estimates of relative risks.

The study was only conducted among professional drivers of long-haul trucks, and precludes generalisations to populations of “normal” drivers of light vehicles.

26 Assessment of driver fatigue, distraction and performance in a naturalistic setting

Barr, L.C., Yang, C.Y.D, Hanowski, R.J., Olson, R. (2005). Assessment of driver fatigue, distraction, and performance in a naturalistic setting. In: *84th Annual Meeting of the Transportation Research Board,* Washington D.C.

Objectives: This is a data mining study using that data gathered in Hanowski et al. (2003), referred to here as the L/SH data set. The data had already been analysed in order to see whether fatigue was a factor in the run-up to critical incidences. This present study aimed to revisit the data in order to answer further research questions.

What is the incidence of fatigue among L/SH drivers?

Are episodes of drowsiness associated with operational factors or factors associated with the driving environment?

What are the effects of fatigue and drowsiness on safe driving performance?

What are the relationships among fatigue, distraction and safe-driver performance?

Methods (participants, equipment)

See also Hanowski et al. (2003).

908 h of footage collected in the L/SH study was analysed in three stages.

- The entire video library was reviewed by analysts to identify and document every observed occurrence of drowsy driving. Here various drowsiness indicators (yawns, eye-rubs, eye-closures, slow blinks, bobbing head etc.) were used by an analyst to assess the drowsiness level according to an observer rating of drowsiness (ORD) scale from 1 (not drowsy) to 5 (extremely drowsy). The reliability and validity of this scale had already been empirically assessed. The drowsiness event was timed and its start- and end-points noted according to a standard procedure.
- One thousand of the identified drowsiness events and baseline events (in which the driver appeared alert and awake) were then analysed for three minutes preceding the end-point of the event. Every fatigue event with ORD = 4 or over was analysed. To make up the 1000 events, an equal ratio of ORD = 2 or 3 events were then randomly selected to achieve a 75:25 ratio fatigue to baseline events. Each event was analysed for PERCLOS (see Hanowski et al., 2003) and two new variables, EYETRAN -- the number of driver eye glances from one direction to another -- and EYESOFF -- the proportion of time driver looks away from the forward roadway.
- Finally, the analysts recorded for each event the following:
    - demographics for the driver (age, experience, shift patterns)
    - sleep quantity and quality for the driver (from wrist activity monitor)

- environmental conditions (weather, visibility, road surface, ambient light, road type, number of lanes, traffic density).

Finally, a random sample of ORD4 and 5 events along with matched baseline events were selected to observe secondary activities during fatigued and alert periods.

Results: 2 745 fatigue events were identified from ca 900 hours and 38 000 miles of driving. That is 3.1 events per driven hour.

Across drivers, 3.5 per cent of overall time was spent being drowsy.

To account for exposure and the severity of fatigue, a measure called the fatigue index was developed for each driver. It is the sum of the ORD rating for each fatigue event divided by the total number of hours of driving data analysed. The median value for all drivers was 7.35, which was used as a threshold to define high- and low-fatigue drivers.

Statistical tests using the variables collected showed that younger, less experienced drivers had a tendency to be more fatigued.

Logistical regression analysis (using fatigue-event or not as dependent variable) controlling for age showed that severe drowsiness was more than twice as likely to occur between 6.00 and 9.00 am, and that ca 30 per cent of all fatigue incidences occurred in the first hour of the shift.

Stepwise regression on PERCLOS ratings for the three-minute intervals showed it was associated significantly with time of day, sleep quality, road type and daylight.

Heavier traffic and poor visibility were related to a decrease in PERCLOS.

Both EYETRANS and EYESOFF were significantly higher for drowsy driving versus baseline driving, suggesting that fatigue is linked to reduced attention while driving. Importantly, however, these variables were highest for less severe fatigue events (see implications).

Analysis of 300 of the more serious fatigue events led to a suggestion that drivers seek to maintain a certain level of workload in order to keep fatigue at bay. When they are alert they tend to maintain workload by engaging in distraction activities such as reading, eating or using the phone, but when they are fatigued, and the effort required increases, they reduce these activities and focus more on fatigue counter measures such as scratching, stretching, adjusting posture.

Implications: ORD is used to operationalise analyst assessments of driver drowsiness. Use of this scale by different studies would allow for cross-study comparisons. Other studies show it is reliable and valid.

This study provides a useful analytical framework for ND studies of drowsiness.

The high incidence of fatigue early on in the shift may reflect the drivers waking up, yawning and stretching. Evidence that this fatigue is linked to a higher risk of critical incidents is given in another abstract (Hanowski et al., 2007)

Measurement of reduced driver attention is consistent with those drowsy driving models that describe the slow withdrawal of attention and reduction of effort, leading then to a more dangerous “tunnel vision” syndrome, in which the driver scans the environment only minimally. This is worth further exploration.

Limitations: What does the incidence of 3.1 events per hour of driving mean? These events are mostly ORD2 events, in which the rater classifies the driver as ”slightly drowsy”. Does being slightly drowsy affect driving behaviour? The fatigue index is a better measure but what is the basis for choosing the median value in order to define high- and low-fatigue drivers? How do we know it means anything in terms of fatigue-influenced driving?

How do we learn about causality of those factors significantly associated with fatigue? Could the video be analysed sequentially to do this?

Organisational factors are not considered. No job design or occupational variables are recorded (e.g. flexibility of working hours, time to destination, stress).

Human factors are not considered i.e vehicle-driver interactions (e.g. are some cabins too “cosy”?).

What can be done to increase the meaning of the results for the organisation?

How many researchers did it take to review 908 h footage?

EYETRANS an EYESOFF were new measures with assumed validity -- one might question the meaning of EYETRANS for fatigue.

27 A comprehensive examination of naturalistic lance-changes

Lee, S. E., Olsen, E. C. B., Wierwille, W. W. (2004). *A comprehensive examination of naturalistic lane-changes.* Report No: DOT HS 809 702. National Highway Traffic Safety Administration (NHTSA), Washington, D. C.

Objectives: It has been estimated that lane change crashes account for approximately 4 to 10 percent of all crashes, and 0.5 to 1.5 percent of all traffic fatalities per year. Knowledge about lane-changing behaviour can be used in the designing of technology such as Collision Avoidance Systems to minimise the frequency and severity of lane-change accidents.

The main objective of the paper is to understand driving behaviour prior to the lane-change. More specifically, various knowledge gaps are identified in the paper, and it is aimed at gaining knowledge that can fill these gaps. The following research needs were identified:

- Investigate lane-changing behaviour by means of naturalistic data (as opposed to experimental research)
- Investigation of eye-glance patterns related to lane-changing behaviour. Do eye glances follow a pattern for certain categories of lane changes?

- How often do various types of lane changes occur?
- Investigate lane change data for different environments (US highway versus Interstate; suburban/rural versus urban roadways; hilly terrain)
- Investigate lane change behaviour for various vehicle types (e.g., sedans and SUVs)
- Provide information required for lance change CAS design, e.g., information about the most prevalent glance locations of drivers preparing to make a lane change; information about drivers' use of turn signals.

Methods: 16 drivers who normally commuted more than 40 km each direction participated in the study. Half commuted on interstate while the other half commuted on a U.S. highway. There were two research vehicles, one sedan and one SUV, and each participant drove each car for ten days. The sample was balanced with respect to gender, and age range was from 20 to 64 (M=40.8, SD=12.2).

The study used a mixed-factors experimental design including three between-subjects variables (gender, driver type – usually drives sedan or SUV, route) and one within-subject variable (vehicle type – sedan or SUV).

The vehicles were instrumented, and the data collection system included video (i.e., five-channels to record heads/eye position and outside views of the front, rear, and rear sides), sensor (velocity, steering, acceleration, and pedal and turn-signal use), and radar equipment (facing forward and rearward, providing information about surrounding vehicles).

A lane change maneuver was identified by video review and categorized by maneuver type, direction, severity, urgency and success/magnitude. A lane change started when the car first moved laterally and ended when the car was settled in the destination lane. Examples of maneuver types are slow lead vehicle, return, enter, and exit/preparation to exit. Severity was rated on a 7 point scale from 1=unconflicted to 7=physical contact, and urgency was rated on a 4 point scale from 1=not urgent to 4=critical. Success/magnitude was categorized as single lance changes; passing maneuvers made within 45 seconds; multiple lance changes; unsuccessful.

Results: Analyses were made both for the full set of lance changes observed, and a more in-depth analysis of a sample of 500 lane changes. Results from the analyses of the full set of lane changes showed that a total of 8667 lane changes were conducted. Mean duration of all lance changes was 9.07. 91 percent were uneventful, and no crashes were observed. Few differences based on the independent variables were observed in terms of frequency, duration, urgency, and severity. However, sedan drivers made more lane changes than SUV drivers.

Most lane changes were to the left, with a mean duration of 11 seconds. Of all lance changes, 83 percent were single, 12 percent passing, 3 percent multiple and 1 percent unsuccessful/partial. Slow lead vehicle lane change was the largest category (37 percent) with a mean duration of 13 seconds, supporting the notion that lane changes to a high degree are cause by a slower lead vehicle. All in all, lane changes were low in severity and urgency, and 91 percent of all lane changes could be accounted for by a two-way distribution of low severity and low urgency (rated 1 and 1).

Results from the in-depths analyses included all higher severity lane changes and focused on the following additional analyses: steering, lateral acceleration, velocity, braking, turn signal use, eye glance patterns, eye glance probabilities, distance, relative velocity and TTC to forward and rearward proximal other vehicle. Results showed that there was a weak tendency indicating that higher speed at lane change initiation was associated with higher severity and urgency. However, analysis of steering, lateral acceleration, and braking maneuvers did not enhance the understanding of lane change behaviour.

Eye-glances were analysed for the three seconds prior to lane change initiation, and results indicated that there was at least one glance (mean time=0.8) to the forward view during these three seconds. Turn signals were used in only 44 percent of the time, with more signal use for left lane changes (48 percent) than right lane changes (35 percent).

Limitations: The study was conducted in southwest Virginia and all lane changes occurred in a hilly section of the area, thus, generalization of the results should be limited to such areas. In particular, the authors note that although traffic density was high, it was probably lower than what is expected in urban areas. Thus, forward and rearward envelopes will probably be smaller in an urban area than what is reported in this specific study.

28 An exploratory analysis of truck driver distraction using naturalistic driving data

Barr, L.C., Yang, C.Y.D., Ranney, T. A. (2003). An exploratory analysis of truck driver distraction using naturalistic driving data. In: TRB *2003 Annual Meeting DC-ROM*, Washington D.C.

Objectives: In this pilot study, naturalistic observation was used in order to investigate frequency and duration of various distraction-related activities among truck drivers. More specifically, the relationship between driving distraction and eye glance behaviour was investigated by selecting a subset of distraction events and conducting an analysis of the driver's eye movements.

Methods: This was a pilot study with six truck drivers as participants. They were all males between 19 and 39 years old. The participants were selected in a non-random fashion, i.e., they were known to engage in distractive activities.

Five small video cameras were installed in each truck as follows: 1) forward looking camera capturing the forward road scene, 2) driver's face camera capturing facial expressions, eye lid closure, glance position, and head turns, 3) left side and 4) right side cameras aiming towards the rear, and 5) rear-looking camera capturing the traffic situation behind the vehicle. The video cameras activated when the truck's engine started, thus, distractive events were only recorded when the vehicle was in motion. The eye glance analysis consisted of 10 sample observations that were selected for detailed analysis. A video clip for a 30 seconds distractive activity would be 270 seconds altogether, i.e., 120 seconds preceding and 120 seconds following the 30 second distraction activity. Data reduction was conducted using the software program Micro DAS MPEG Video Player

Results: Results showed that 4329 distracting events occurred during the 121 hours of data that were analyzed, which means that distractions were observed in approximately 52 percent of the total driving time. Drivers spent over 80 percent of the time looking at the road ahead at baseline (i.e., when not involving a distracting activity). Increases in eye glance durations to the side mirrors and inside the truck were related to distractions such as talking on the phone and tuning the radio.

Naturalistic driving observation as a method is discussed in the paper. In particular, it is emphasised that naturalistic observation is time consuming and labour-intensive and that one should be aware of mental fatigue when analysing such large quantities of data. Moreover, the authors stress that proper training and experience of data analysts are of great importance (a learning curve was observed among analysts of eye glancing data), and that optimal location for video camera placement must be piloted and determined prior to data collection process

29 An on-road study to investigate fatigue in local/short haul trucking

Hanowski, R. J., Wierwille, W. W. Dingus, T. A. (2003). An on-road study to investigate fatigue in local/short haul trucking. *Accident Analysis and Prevention,* 35, 153-160.

Objectives: Although there has been much research into hours-of-service regulations and drowsy driving among long-haul drivers in the USA, little is known about whether fatigue is also a problem for local or short haul (L/SH) drivers[9]. Eleven focus groups were therefore carried out across five states by the Federal Highway Administration in an attempt to gain L/SH driver perspectives on safety issues, including fatigue. The top five critical issues related to dangerous incidents across all the sessions were in rank order (i) other car drivers; (ii) stress due to time pressure; (iii) inattention; (iv) roadway/dock design; (v) fatigue. Fatigue-related issues in terms of importance were (i) sleep; (ii) hard physical work; (iii) heat; (iv) waiting to unload; (v) irregular mealtimes. Fatigue was not as critical a factor as for long-haul drivers and, rather than being caused by prolonged driving, it was caused by out-of-hours factors such as sleep patterns.

These results were used to inform and complement this second phase of the study, a field experiment using naturalistic observations of driver fatigue lead-

[9] Driving typically no more than 170 km from the vehicle home base.

ing up to critical incidents, complemented by self-reports on the day of the incident and physiological measures of driver sleep patterns.

The data generated here is mined in a separate report, as described in abstract Barr et al., 2005.

The research questions in this article are:

- Is fatigue an issue in L/SH operations?
- What is the level of fatigue when drivers are involved in critical incidents?
- What guidelines can be generated to address fatigue in L/SH trucking?

Methods: 42 male L/SH drivers from two companies. The trucking *companies* were paid for participation, and drivers also paid individually.

Four truck types were used representing typical in-service trucks. They replaced the drivers' normal trucks.

There were three data collection systems, each described as unobtrusive (cameras < 3cm^2) and reliable for 24 h collection. There were five cameras in each truck system, giving an all-round view: one to capture the forward road; one for the driver's face; one mounted on each wing mirror facing the rear; and one to capture the road behind. The images were arranged into four quadrants forming a single image (the two mirror cameras formed two halves of one of the quadrants).

There were eleven sensors in each truck, which were calibrated after mounting and which were checked every day to insure against malfunction. These measured accelerator deflection; lateral and longitudinal acceleration; ambient light; object-proximity during reversing; audible utterances in the cab; direction signals; distance; velocity; reverse gear; brake depression; and steering wheel position and velocity. There was also an incident push-button for the driver to press.

Each driver drove for two weeks, working four or five days a week. At the end of each day the driver was asked to give self-reports. The drivers were also asked to wear wrist activity monitors to measure their sleep quantity.

Data from the cameras and sensors was reduced around critical incidents, defined as 'unexpected event resulting in a close call or requiring fast action on the part of a driver to avoid a crash', and compared with corresponding data from the self-reports and activity monitors.

Two variables were assessed to monitor fatigue occurring in the three minutes preceding the critical incident: PERCLOS (proportion of time drivers eyes 80-100% closed) and OBSERV (observer rating of drowsiness on 0-100 scale), both shown to be reliable and valid in other studies.

Results: 249 critical incidents were recorded, of which 77 were classified as driver-at-fault. However, just two of the 42 drivers involved were responsible for 20 of these 77 incidents and eight were responsible for 46 of them.

According to both PERCLOS and OBSERV measures, fatigue was present at higher levels immediately prior to driver involvement in at-fault critical incidents than prior to incidents where other drivers were at fault.

Setting arbitrary threshold values for the fatigue measures resulted in claims that fatigue was a likely contributor in 21 per cent of critical incidents in which the driver was at-fault.

Drivers involved in at-fault incidents judged to have been fatigued had less sleep according to both self-reports and the activity monitor. Sleep hygiene may therefore impact on-the-job performance.

Drivers spending less time loading tended to be at-fault for fatigue-related critical incidents, suggesting that physical activity may be stimulating rather than fatiguing.

Younger drivers appeared to be involved in more at-fault incidents and to be more fatigued prior to incidents.

Implications: Fatigue is suggested as an issue in L/SH operations, but it is difficult to give recommendations to the organization while the causes of that fatigue are found off-duty.

Limitations: Lack of detail about self-report measures collected, and how they were collected.

We know little about when the activity monitors were worn.

We know little about how often the sensor or camera data must be discarded and why, or any quality control procedures in data selection.

How exactly was the sensor data used? Was it all necessary? Which measures were more useful? Comment about this might avoid others collecting and analyzing data unnecessarily.

In other reports the same authors criticise this study for being carried out over too short a time period (two weeks).

No experimental variables are manipulated so it is difficult to determine cause-effect relationships. But this is always the trade-off in true ND studies?

Arbitrary threshold values chosen for fatigue measures. What is their basis?

Despite and operational definition, the selection of some of the critical incidents must require subjective judgment by video analysts. How were the analysts trained? Interrater reliability?

Drivers would know the study was about fatigue because they had to wear sleep activity monitors and report daily on their fatigue level. Is this study truly naturalistic?

As in the previous study, a small percentage of drivers are responsible for most incidents. How much can we generalize?

We are left uncertain as to why fatigue present other than the link to sleep hygiene. An assumption is implicit that poor sleep hygiene is caused by ‘off-duty activity’, which leads to fatigue on the road the next day. Longer term sleep loss, organisational arrangements, safety culture and individual differences, among other factors, are not considered.

How do the conclusions fit with other findings about fatigue as a cause of critical incidents or accidents among L/SH drivers, long-haul drivers or the general driving population?

30 Independent driving pattern factors and their influence on fuel-use and exhaust emission factors

Ericsson, E. (2001). Independent driving pattern factors and their influence on fuel-use and exhaust emission factors. *Transportation Research Part D: Transport and Environment*, 6, 325-345.

Objective: The main aim of this study was to find driving pattern factors and investigate which of these that have an effect on emission and fuel consumption per kilometres.

Methods: 19 230 driving patterns from real-traffic in an urban area were examined. Emission and fuel-use factors were calculated for driving patterns of a subset of 5217 cases.

Results: Regression analyses showed that nine of the driving pattern factors had considerable environmental effects: Fuel consumption was affected by the factors for acceleration with high and moderate power demand, stop, speed oscillation, extreme acceleration, speed 50-70 km/h and moderate engine speed at gears 2 and 3. Emissions of HC were primarily affected by acceleration with high power demand and extreme acceleration. NO_x emissions were affected by factor for acceleration with high power demand, extreme acceleration, engine speeds > 3500 rpm and late gear changing from gears 2 and 3.

Implications: As the different factors identified in this study are independent, it can be concluded that speed in itself does not cause large environmental problems in urban traffic, and lowering speed limits for traffic safety reasons is not a problem from an environmentally point of view. Rather, focus should be on changing environments, drivers and vehicles in a way that does not promote heavy acceleration, power demand and high engine speeds. How to best manage this should be subject to further research.

31 A preliminary assessment of algorithms for drowsy and inattentive driver detection on the road

Tijerina, L., Gleckler, M., Stoltzfus, D., Johnston, S., Goodman, M. J., Wierwille, W. W. (1999). *A preliminary assessment of algorithms for drowsy and inattentive driver detection on the road.* Report No. DOT HS 808. National Highway Traffic Safety Administration (NHTSA), Washington D. C.

Objectives: The report claims that a method is needed for the observation and assessment of a) drowsiness and b) indicators of drowsiness in naturalistic driving. Two reasons are given. First, other methods (driver self-reports, crash investigations) may underestimate both the occurrence of drowsy driving and its contribution to road accidents. Second, such a method could be used to develop a reliable and valid sleepiness indicator that could a) form part of an in-car warning system to increase driver awareness of drowsy states, and b) be used to measure the effects of road safety interventions such as information campaigns or alterations to road design (e.g. rumble-strips).

To help achieve this, the report tests in a real-world setting an algorithm developed in simulator studies to predict sleepiness among drivers (where sleepiness is defined as the proportion of manually observed cumulative eye closure time). The algorithm enters values on certain variables into a multiple regression equation to predict sleepiness. Several or all of the following are entered as predictors in the equation: steering wheel velocity, number of times steering wheel movement exceeds 5 and 15 degrees, average deviation from mid-lane position, proportion of time outside lane boundary, lateral velocity, and deviation in yaw rate.

The research questions are:

- How often does drowsiness occur in naturalistic driving among non-commercial drivers?
- Can a set of sleepiness indicator variables developed to predict eye closure events in driving simulators be used to predict eye-closure events and/or degraded lane-keeping behaviour in real-world driving?
- Is there any evidence that a) voluntary lane deviations and b) driver distraction can explain false positive results generated by the algorithm?

Methods: The recruitment was targeted at students (newspaper ads), shift-workers (management announcements, flyers, TV announcements in the organization), and military personnel (newspaper ads and flyers) in central Ohio. For inclusion, the students and military personnel had to be planning a minimum 5-hour drive during weekends or breaks, and the shift workers a minimum 45-minute commute. A screening process was used in which the volunteers had to be healthy (including no sleep-related disorder), have a good driving record, drive a passenger car, and have minimum two years driving experience. After that, those participants who were judged most likely to experience drowsy driving were selected. There were seven participants, all male and in their early 30s apart from the shift-workers who were in there early 50s. They drove their own cars, fitted with equipment, and there were five different car types. Participants were paid between $310-390. At the end of the test participants were interviewed informally about any problems or unusual events that had occurred. An effort was made throughout recruitment and testing not to give any indication that the test concerned drowsy driving.

A data acquisition system of sensors and processing captured the algorithm predictors when the vehicle was traveling over 43 mph. Digitized video of the road scene and driver eye-glance behaviour were taken and synchronized to the engineering data. Infra-red lighting allowed video recording at night. All data captured at 30 Hz sampling rate. The eye-glance video was later manually reduced to obtain eye closure data.

The reduced video and engineering data was analysed in three-minute periods or ‘epochs’. For each epoch there had to be 2.5 minutes of viable data available (e.g. video data not viable due to poor lighting / equipment malfunction, engineering data not viable due to missing lines on road, reflections in bright sun).

Results: Drowsiness occurred in 20 of the 283 three-minute periods analysed, where drowsiness is defined as a cumulative eye closure of 0.012 per cent or 2 seconds or more in a 3 minute epoch. Although each of the seven participants had at least one drowsy driving epoch, two of them accounted for most of the epochs observed. The longest single bout of drowsy driving was 13 seconds. Lane deviations, which were defined either as lane exceedance over 12 s in an epoch or mean square deviations from centre of 3.0 ft^2 or greater, occurred almost exclusively in the epochs derived from a single participant.

Most of the results describe the testing of variations on a model of predictors (the predictors collected) for the following as dependent variables:

- eye closure
- eye closure and lane deviation
- lane deviation

The original model of predictors, claimed to have a correct eye closure detection rate of 49 per cent in simulator studies, was found to have a 35 per cent detection rate in real-world driving. As in the simulator, the set of indicators tended to predict many false positives i.e. predicted at least 0.012 per cent eye closure where this was not observed. The number of false positives was substantially reduced if model was used to predict drowsiness *or* degraded lane performance, suggesting that many of the false positives were generated by degradations in lane performance.

An important question was therefore whether these lane degradations were in turn associated with drowsiness. Analyses using yaw rates also showed some limited evidence that these false positives were in part due to voluntary strategic lane deviations from drivers (i.e. cutting corners to save time or reduce centrifugal force). A hypothesis that false positives were due to lane deviations caused by eyes-off-road-ahead (driver distractions) was also tested by manually reviewing glance locations in false positive and true negative epochs, but little support was found. The data was more consistent with the hypothesis of lane deviations caused by drivers attempting to fight off drowsiness.

In attempting to improve the set of predictors, a best model was derived that simply uses observed mean square lane deviation to predict drowsiness or degraded lane performance. Here the hit rate is 63 per cent and the false positives reduced to 0 per cent.

Implications: For the data from seven drivers, seven per cent of classified periods were defined as drowsy periods. This has implications for drowsiness as a problem in real-world driving.

The report finds that a set of physical indicators developed in a simulator as a predictor of drowsiness has reduced validity in real-world driving; it generates many false positives.

Specifically, variables based on steering wheel movements and lateral velocity appeared to have no predictive power in the real world.

ND observations suggest that drivers do not have as much ‘room to move’ on real roads than on simulator roads because the potential risks are greater.

If one includes lane deviation along with eye closure in the variable to be predicted, false positives (which would be annoying for drivers) can be reduced to zero and over 60 per cent of incidents predicted.

Lane-keeping seems to be important for predicting drowsy driving, according to these data, but there is a problem: not all lane-keeping deviations are drowsy-driving related.

The question the report raises is therefore whether it is useful to raise the driver’s attention to the possibility of either lane deviation or drowsy driving, but not drowsy driving alone.

If some of the lane deviations are drowsiness-related, as the report gives some evidence for, such a device may indeed be worthwhile on balance.

Limitations: Only seven drivers were tested, and they were selected on the basis that they were likely to drive while fatigued. This limits the extent to which generalizations about the incidence of drowsy driving can be made to the normal driving population.

Most of the drowsy driving occurred for two of the participants and lane deviations occurred almost exclusively during the driving of one participant. Indeed, much of the time is spent trying to predict the observed lane deviation and eye closure, and account for false observations, for one participant (who possibly has an unusual driving technique!).

There is a lack of information in the method. We do not know how long the participants were monitored, how long their trips were, or exactly how the cameras were fitted (e.g. where were the cameras and how many cameras?).

We know that ‘lane tracking data were frequently missing’ but we do not know why or how much data was lost due to quality control criteria, and are therefore not informed about the size and type of problems associated with data collection. We cannot therefore attempt to improve the situation in the future.

We are not informed about inter-rater reliability during manual data collection. Is this because there was too much material to analyse or because it wasn’t done?

There is on the whole some lack of clarity about how the data reduction was done.

It would have been interesting to have more insight into the reasons for the fatigue, but the authors make a good point that this would arouse awareness that the study is about fatigue and threaten its naturalistic nature.

The authors themselves point out that fatigue may not always result in lane deviations where there is selective withdrawal of attention by the driver. If this is true, the model is limited in that it will not detect those “lost in thought” crash contributors.

The need for three minutes of data analysis precludes the algorithm’s use as a lane deviation warning system.

The authors are trying to develop a way to indirectly monitor eye closure but others are trying to develop direct methods (eye-closure detection devices rather than algorithms based on other indicators).

Finally, more robust systems (ones that process optical field flow rather than lane lines) could have led to a more complete set of data for analysis than that obtained here.

Appendix II: Summary of European projects

32 INTERACTION (INTERACTION 2009)

INTERACTION is an ongoing project funded by the European Commison 7th Framework Programme. 12 partners from 9 countries are involved in the project which is led by INRETS (France). The project started in 2008 and is planned to end in 2012.

Objectives and methods: The main objective of INTERACTION is to use various methods to study and understand driver interaction with mature in-vehicle technologies in the market. More specifically, the following main research objectives will be addressed:

- Why, when, where and how drivers use IVT?
- What are the patterns of IVT use in everyday driving?
- What are the individual factors that explain or not the adoption of IVT by drivers?
- What are the differences or similarities between countries and their reasons?
- What are the actual supports to the driving task given by the systems? Are there involuntary or voluntary misuses of systems?
- Can these systems induce unexpected unsafe behaviour and skills?

In order to address these issues, a range of well-established and new methods will be applied: questionnaires (self-report measures), focus groups, experimental observation, and naturalistic driving observation. For the present review it will be focused upon the part in which naturalistic driving will be applied.

SWOV is the leader of the work package dealing with naturalistic driving observation (WP4). In this part of the project, approximately 20 cars will be equipped with unobtrusive measuring devices (sensors, mini-cameras) which allows for recording of behaviour as well as the environment. The main objectives of this particular part of the INTERACTION project is:

- To observe a sample of drivers at the wheel of their own vehicle
- To identify the drivers' patterns of IVT use in everyday life and their implication for safety

The process for selection of in-vehicle functions is a seven step process:

- definition of the relevant criteria to select in-vehicle functions
- identification of the major makes of cars in Europe in terms of sales
- definition of a typology of available In-vehilce functions in the European Market

- checking of the availability of the functions according to the makes and the car categories distribution of makes and car categories amongst the sales of new cars in 2007 in the participant countries

The most relevant technologies to be investigated in the INTERACTION project is a) longitudinal control systems (Cruise Control, Speed Limiter, Adaptive Cruise Control), b) trip information systems (Navigation systems), c) infotainments systems (cell phones).

Research question addressed: Identify drivers' patterns of use of IVT in everyday life, and the implication of such use for safety

33 SAFER, Test Site Sweden (TSS) – Field Operational Test

Objectives: The main aim of the TSS FOT phase I was to perform a small-scale Naturalistic FOT in order to assess the methodology-chain that will be used in large-scale FOTs. Thus, the focus was on enabling the capability to assess the effect of Advanced Driver Assistance Systems (ADAS) on traffic safety. In particular, the focus was on building up competence, as well as evaluate and establish tools needed to perform such FOTs.

Methods: The study was designed so as to perform and assess the FOT methodology chain, which describes the process form acquiring data in the vehicles (stage 1), uploading data to be stored in a database (stage 2) and accessing the database through a search interface to enable data analysis (stage 3). Further, the project was divided into three tasks reflecting the three stages of the FOT methodology chain:

Task1: Requirements specification and purchasing of equipment: In this task, close collaboration was established with the University of Michigan Transportation Research Institute and Virginia Tech Transportation Institute in order to learn from their experience.

Task 2: Instrumentation of Data Acquisition Systems and administration of data collection: In this task, the practical administration associated with the data collection in the field was dealt with; including: definition of dependent metrics, set-up of logging equipment and sensors, vehicle instrumentation, and set-up of data management and storage system.

Task 3: Data analysis: A list of analysis tools was identified and the development focused on live access to data and video, software for data visualization, and post-processing analysis and tools (Matlab scripts, plots, database queries etc.).

For the data acquisition process, two vehicles were selected: Volvo Cars S80 and Volvo Trucks FH12. These were equipped with data acquisition systems, and in total about 200 hours of driving data were recorded from slightly more than 100 drivers. The main sensors for acquiring data in the logger were:

- GPS
- Accelerometers (longitudinal and lateral)

- Vehicle CAN-bus data including steering wheel angel, pedal position, gear lever, yaw rate, engine speed
- Video cameras
- Foot location sensors (on pedals)
- Incident button

In sum, the project successfully implemented and evaluated the FOT Methodology Chain. However, a number of critical stages in the chain were identified that would require much more effort when running a large scale FOT, e.g., extra work with the data acquisition system, further quality assurance of the vehicles, further specification of sensors, performance indicators and hypotheses. In particular, the methodology chain would need to be complemented with detailed tasks for breaking down research questions.

34 SeMiFOT and other Swedish FOT activities

Objectives: The objective is to use naturalistic driving as a data collection tool in order to conduct various Field Operations Tests. This includes natural driving with no special instructions in participants own vehicles and without any experimenter present. In particular, the SeMiFOT goals are

- to further develop the naturalistic FOT method into a powerful tool for a) accident research, and b) evaluation of safety, efficiency, and usage and acceptance and c) countermeasure innovation and development
- to verify the naturalistic FOT methodology at an intermediate scale – at a large scale than TSS FOT, however smaller than EuroFOT

Environment sensing and continuous logging is used to assess the relationship between various factors:

Driver factors:

- Permanent: Age, Experience, Style
- Transient: Drunk, Tired, Distracted

Vehicle factors:

- Permanent: Vehicle type
- Transient: ADAS

Environment factors:

- Permanent: Speed, Road types
- Transient: Weather, Lighting

These variables are to be investigated in relation to:

- Crash risk (Relative risk, Population attributable risk)

- Driver behaviour (control behaviour , attention, decisions, usage/adoption, event involvement
- Countermeasure effectiveness (ADAS, road treatments etc.)

35 sim^{TD} Safe and Intelligent Mobility – Test Field Germany

Institution/Country/Coordinator: Daimler AG, Group Research and Advanced Engineering/Germany/Daimler AG

Objectives: simTDwill put the results of previous research projects into practice. For this purpose realistic traffic scenarios will be addressed in a large-scale test field infrastructure around the Hessian city of Frankfurt. The project will also pave the way for the political, economic and technological framework to successfully set up car-to-car and car-to-infrastructure networking. Various issues are addressed in the present study:

Traffic Monitoring of traffic situation and complementary information/basic functions

Data collection in the infrastructure side

Data collection by the vehicle

Identification of road weather

Identification of traffic situation

Identification of traffic events/incidents

Traffic (flow) information and navigation

Foresighted road/traffic information

Road works information system

Advanced route guidance and navigation

Traffic management

Alternative route management

Optimized urban network usage based on traffic light control

Local traffic-adapted signal control

Driving and safety

Local danger alert

Obstacle warning

Congestion warning

Road weather warning

Emergency vehicle warning

Driving assistance

In-vehicle signage/traffic rule violation warning

Traffic light phase assistant /

Traffic light violation warning

Extended electronic brake light

Intersection and cross traffic assistance

Additional services

Internet access and local information services

Internet-based usage of services

Location-dependent services

Methods: The overall simTD test fleet comprises an internal fleet with up to 100 controlled test vehicles as well as an external fleet with approximately 300 vehicles. The internal simTD fleet of test vehicles comprises 20 core vehicles with expert drivers. 80 further vehicles are driven by persons without special training.

The expert drivers will be asked to work together locally and on their own initiative to create certain scenarios. The other drivers' reaction to the respective scenario can then be used to evaluate its efficiency, safety and acceptability of functions. The external fleet with about 300 vehicles is needed to create the specific traffic load for this scenario.

36 AOS

Institution/country: Dutch Ministry of Transport and Connekt/ITS Netherlands

Objective: Conducting field operational tests of five driver assistance systems that can help prevent accidents involving lorries: 1) headway monitoring (HMW), 2) forward collision warning (FCW), 3) adaptive cruise control (ACC), 4) lane departure warning assist (LDWA), 5) directional control (DC).

Methods: The FOT will test five different driver assistance systems that can help to prevent accidents involving lorries. In all, 3000 trucks are involved in the project. Separate registration systems that record drivers' behaviours, will also be tested. The FOT will address the three most common types of accidents: rear-end collisions, side collisions, and single-vehicle accidents.

The AOS project consists of four subprojects:

- Retrofit project: 1,200 vehicles (testing HMW/FCW+LDWA+ ref. group)
- Drivers project: 600 vehicles (testing HMW/FCW+LDWA+BBFB+ ref. group)
- OEM project: 700 vehicles (testing DC+LDWA+ACC+ ref.group)
- Test track tests: Test track measurements with anti-tilting sensors

Driving with and without ACC: Evaluated differences

Institution/country: Lehrstul für Ergonomie, Technische Universität, München

Objectives: The goal of the experiment was to get behavioural data for unassisted (natural) driving, and to compare it with ACC characteristics afterwards.

The experiment was done following the concept of a Naturalistic Driving Studies (NDS). NDS can be viewed as a specific type of field experiment. In terms of such experiment, the test subject and object are put into their "natural" operating environment, and the experimenter rather observes than guides the investigated situations.

The experiment was performed for typical highway situations during which drivers' natural behaviour was observed. Analysis of collected data was performed for different driving measures, such as time gap (TGAP, also sometimes referred to as the time distance) and distance to the car in front. These measures were taken during maneuvers performed by the driver during their unassisted natural driving. Results of descriptive analysis of taken measures are then compared to the ACC assisted driving values that are expected for these maneuvers. In this work, the functionality of ACC and its usability in different highway traffic situations are examined. It is shown, in which particular situations ACC could be improved through better anticipation of the driver's behaviour. The goal of the presented study was to apply the technique of NDS experiment in order to examine typical highway maneuvers and afterwards to specify the situations, in which ACC assisted driving behaviour significantly differs from the unassisted one.

Methods: Six drivers (4 male, 2 female) participated in the study. They were between 18 and 52 years old (mean = 32 years, s.d. = 14 years). Each of the participants had to drive the highway course. This course was driven on the three-lane and two-lane highways with relatively high traffic density. The car driven by participants was BMW 325 E91 provided by BMW Group. The driving measurements of own vehicle and data of other relevant cars were recorded at 25 Hz frequency. For additional help during the analysis and situation classification the synchronized video stream was taped.

In this experiment, three typical types of highway maneuvers were examined; 1) changing lanes, 2) approaching departing vehicle, 3) allowing other vehicle to overtake. The goal of this examination was to determine the minimal distances and corresponding time gaps which are characteristic for approaching the vehicle in front during performance of certain maneuvers.

Before comparison with ACC assisted driving values, dependent measurements for each type of maneuver were sorted for better overview into six sub-groups depending on the speed of the own vehicle at the moment when $dist_{min}$ and $TGAP_{min}$ were taken. Overall, following speed sub-groups were considered: 80-100 km/h, 100-120 km/h, 120-140 km/h, 140-160 km/h, 160-180 km/h, and >180 km/h.

Results: The results of comparison show that drivers frequently perform the maneuvers with shorter distances to the cars in front as well as smaller TGAPs than it is allowed by ACC under the same circumstances, i.e. considering driven speed. The analysis of overtaking maneuvers showed speed influence on minimal distances, but not on corresponding TGAPs. The drivers try to keep constant TGAPs independent of the driven speed.

53% of overtaking maneuvers were performed with $TGAP_{min}(M1)$<1s. 17% are with $TGAP_{min}(M1)$ less than 0.6s, which is considered to be a critical time gap. However, the overall mean TGAP for overtaking still lies above 1s (mean = 1.07s, s.d. = 0.54s). When approaching a departing vehicle, $TGAP_{min}(M2)$<1s is 83%, and $TGAP_{min}(M2)$<0.6s is approximately 30% (mean = 0.82s, s.d. = 0.5s).

No speed influence could be proven for TGAPs also when allowing the other car to overtake (Figure 11). Here $TGAP_{min}(M3)$<1s is 73%, and $TGAP_{min}(M3)$<0.6s is 30% (mean = 0.84s, s.d. = 0.43s).

Discussion and conclusions: The measures of distance to the car in front and TGAP were investigated in NDS experiments performed for typical driving situations on the highway. The characteristic values for examined types of maneuvers were determined. They were later compared with corresponding ACC-system parameters. Results indicated that drivers tend to reach shorter distances to the cars in front and smaller TGAPs than ACC allows for certain types of maneuvers.

Such behaviour of the drivers can be explained through the human ability to better anticipate the upcoming traffic situation in comparison to ACC-system. Therefore, subjectively estimated safe distances and corresponding TGAPs are sometimes smaller in comparison to those typical for the system. Due to limited anticipation capabilities of ACC, the system should legitimately maintain longer safe distances and larger time gaps to relevant traffic participants. These should be sufficient to allow the driver to overtake the control over a driven vehicle if anticipation of the system fails and leads to critical situations. However, the discrepancy between subjectively safe behaviour and the one influenced by the ACC can be reduced through improvements in the system's anticipation of the traffic situation. The resulting system should safely assist the drivers to perform the needed maneuver in their most natural manner without constraining them. This could be done through intuitive and comfortable overriding of the system's functionality, e.g. for the overtaking maneuvers when the blinker is activated.

37 Curve negotiation: Identifying driver behaviour around curves with the driver performance database

Institution/country:

Human-Factors-Consult, Berlin, Germany

Chemnitz University of Technology, Chemnitz, Germany

Ingenieurbüro Lange + Tenzer, Hannover, Germany

Volkswagen AG, Wolfsburg, Germany

Objectives: Approximately one quarter of all accidents outside city limits occur while driving around curves, where assistance systems could prevent the driver from negotiating curves with excessive speed. This study argues that the parameterizing of a Driving Assistant System could be realized with data from realistic, noncritical driving behaviour offered by Naturalistic Driving Studies. The Driver Performance Database presented in this study provides a tool for observing normal, noncritical driving behaviour. The Database contains results from road tests with an instrumented vehicle that were carried out on public road traffic on a predetermined route, which was precisely measured in advance. In addition to vehicle state parameters, we also collected data concerning the driving environment and physiological information. With the Driver Performance Database it is possible to generate different facets of human driving behaviour in a descriptive and normative way, which is illustrated by driver behaviour in curve negotiation.

Methods: In order to collect and evaluate sample amounts of data with NDS, the Volkswagen AG Group Research developed a Driver Performance Database between the years of 2003 and 2005. It is used for the consistent recording of data categories – driver, vehicle, environment – throughout the test, as well as for statistical and analytical evaluation under different, not predefined questions. This methodology makes use of three elements: a predefined reference route, an instrumented vehicle, and a relational data base as an intelligent medium for storage and evaluation of the collected data (Tenzer, 2004).

Reference route. A differential GPS (Niemeier & Thomsen, 2003) was used to measure a circuit of approximately 55 kilometers of public road near Wolfsburg (Lower Saxony, Germany). This sample contained the curves analyzed in this study. The measurement included mapping out all traffic devices (e.g., highway striping, center lines, stop lines, closed areas) in type and location as well as determining all traffic signs' position and angle toward the road. Furthermore, all intersections and the surrounding area reaching 30 to 50 meters into each of the cross-streets were mapped out, as well as traffic devices and traffic signs. The measurement data were stored in the database as high-precision Gauss-Krüger-coordinates.

Instrumented vehicle. Driver behaviour was recorded with the ViewCar of the German Aerospace Center in Brunswick,Germany. The vehicle was equipped with a positioning system. Drivers' actions (onset of brake and accelerator, steering, gaze behaviour), physiological data (e.g., heart rate), and vehicle state parameters (e.g., speed, acceleration) were recorded using various sensors and the CAN-bus. The geographical position of the vehicle was provided by a differential global positioning system. In areas with poor signaling (forest, tall buildings, and alleys) position data was adjusted by an inertial navigational system. All recorded data were time stamped and saved in the database.

Driving tests. Driving tests were conducted in daily traffic on the reference route under various traffic and weather conditions. Subjects were 6 males and 5 females. They ranged from 23 to 78 years of age and had from 6 to 44 years of driving experience. Each subject completed the course 5 to 6 times on different days in the periods July to November 2004 and March to April 2005, except one subject who dropped out after 2 sessions. At each session subjects drove the course in both directions. They were instructed to drive as they normally would; the experimenter gave directions to follow the course but no further instructions or advice was given. The driver was responsible for the car and all fines. Furthermore, no additional tasks were given to the driver and no special settings had been created. The purpose was to collect data on “normal” driver behaviour.

Driver Performance Database. The driver performance database is a relational database. The design and development team balanced the tasks of creating an open database system with an unlimited data capacity making it extendable to future tasks. Within the framework of database development, a data model was set up according to the requirements of the reference track and driving tests. All sensor data gathered from the instrumented vehicle received a common time stamp. Sensor data and data from the reference track had been linked by geographical position (i.e., easting and northing) of the car.

The outcome is a database in which data as an indicator for driver behaviour is not only saved by its characteristics but also by the situational context.

Data analysis on the example of negotiating curves. Five curves on rural roads were selected for analyzing deceleration behaviour prior to curves and characteristic curve speeds. As participants drove the course in both directions, each curve was negotiated as a left and right turn. Curve 3 (right turn) and curve 4 (right turn) were excluded from analysis because low vehicle speed and thus no deceleration were expected due to the city situated prior to that curves.

Only a portion of the data was available at the time of analysis. From the analyzable 379 curve negotiations, only those performed on dry road surfaces were selected. This resulted in a total of 337 curve negotiations analyzed.

Results and discussion: Noncritical driving behaviour is a data source to parameterize driver assistance systems. In most cases assistance systems will be triggered when drivers exceed prescriptive limits. These limits can be derived from “normal”, noncritical behaviour from a large sample of drivers within an NDS. The methodology introduced here allows a description of driver behaviour with the driver performance database, as demonstrated with the example of driver behaviour within curve negotiation. The results show that there is a range of normal, noncritical driving behaviour while negotiating curves. This driving behaviour can be described by a mathematical equation, in our case a regression formula. However, the results obtained in this example should be validated by further data from studies on noncritical driving behaviour and critical events. A fruitful source of data was obtained from the 100-car study by Dingus et al., (2006).

38 Institution/country: DHV Environment and Transportation, The Netherlands and Cito, the Netherlands

Objectives: Research, driver assessment (among others web-based instrument for driver assessment using video’s of drivers) and, in the case of the driving instructors, assessment of driving instructor competences.

Methods: Video of drivers synchronized with video of the road scene in front of the car and in some cases also behind the car (rear mirror view).

Driver groups: experienced drivers, learner drivers and driving instructors and their learner drivers during driver training.

39 Evaluation of the Pilot Young Driver Coaching Programme

(Fylan and Fylan 2009)

Institution/country: Staffordshire County Council Road Safety and Sustainable Travel Unit/England

Objectives: The main objective of this study was to evaluate young novice drivers and their parents' experiences with a Young Driver Coaching Programme, in which young drivers are mentored through the first year following passing their driving test. A small electronic device was installed in the drivers' cars, and feedback was given on a website for both young drivers and their parents to check. In addition, immediate feedback was given to the driver by means of a LED-light, indicating whether a maneuver was safe (green light) or unsafe (amber and red lights).

Methods: Results from questionnaires administered at the start and end of the pilot are reported. Thus, the present report does not give information about the observed behaviour as such, rather how participating in the program were experienced by young drivers and their parents.

12 participants provided data at two time points (start and end), of which half were males and half females. Their age ranged from 18 to 21, and their driving experience ranged from less than three months to more than two years.

Results: For the present review, only some of these self-report findings are relevant and consequently not all results will be reproduced. However, some of the results are interesting with regard to why and how to get participants to such a program or study.

Young drivers participated in the pilot test because their parents had encouraged them to, because they wanted to improve their driving and gain experience, because they wanted to find out what type of drivers they were, and to prove to others that they were safe and responsible drivers. Main barriers for participating (reported by the participants) were concern for parents monitoring their driving, discussing the results of the programme, and the possibility that they were being checked or spied upon.

As for benefits of having a youngster in the program, parents reported that it gave them reassurance and peace of mind that their child was safer on the roads.

The self-report findings also showed that all but one of the young drivers discussed the feedback with their parents and that they found it easy to do so.

40 2besafe

Background: Powered Two Wheeler (PTW) users are greatly over-involved in serious and fatal crashes. As the number of PTWs on European roads has more than doubled over the last two decades, PTW crashes constitute a great challenge.

The recent MAIDS (Motorcycle Accident In-Depth Study) study of PTW crashes in Europe found that behavioural and ergonomic issues were major contributing factors to PTW crashes. The behavioural and ergonomic factors contributing to accidents involving four wheeled vehicles have been studied for a long time through laboratory and simulator research, observational studies and more recently naturalistic driving studies, leading to countermeasures to reduce fatalities. There is no comparable research for powered two vehicles, and there is a lack of research tools, for example motorcycle simulators to study motorcycle rider behaviour.

2 BE SAFE is a broad-ranging research program that will produce fundamental knowledge on PTW rider behaviour as well as knowledge about the interaction between PTW riders and other road users. The produced knowledge will be used to propose relevant countermeasures to mitigate fatalities and injuries. Its main objective is to target behavioural and ergonomics research to develop countermeasures for enhancing

Powered Two Wheeler (PTW), riders safety, including research on crash causes and human errors, and the world's first naturalistic riding study involving instrumented PTWs.

It involves 29 partners in 14 different countries in Europe, Israel and Australia, divided among research and academic institutes, end-users associations and industrial partners.

Objectives: The innovative program of research targeting behavioural and ergonomic factors contributing to motorcycle crashes focuses on the following scientific issues:

- to analyse the crash causes and human error
- to realize the world's first naturalistic riding study involving instrumented PTWs
- to examine PTW riders' perception and acceptance of risk
- to develop new research tools to support the research program, in-depth research on the factors that underlie driver failures to see PTWs and their riders
- to develop recommendations for practical countermeasures for enhancing PTW rider safety

41 DaCoTA

DaCoTA is an FP7 integrated project that will advance the state of the art in six key areas of road safety data.

Road Safety Policy

(1) DaCoTA will develop a protocol to collect information on road safety management systems and good practice in knowledge-based policy-making. The information will be capable of becoming incorporated to the ERSO.

In-depth Accident Investigations

(2) DaCoTA will identify suitable crash investigation teams within Member States and will assist them to develop the local infrastructure to gather in-depth accident and injury causation data.

Data Management

(3) DaCoTA will develop a road safety data warehouse as a comprehensive and integrated system with aggregate data and information consolidating, organising and making available all existing data and information, necessary for the support of the decision making.

Decision Support

(4) DaCoTA will develop a standardised approach to forecasting casualty trends based on the available data in EU Member States and will use this and other information to compare trends in relation to safety measures. Practical, ready-to-use instruments to support decision-making will be developed using the forecasts' results and, more generally, the information collected in the framework of the project.

eSafety

(5) DaCoTA will develop a new accident causation theoretical model following the work done in TRACE and SafetyNet. It will develop methods to expand the benefits evaluations from a few countries to as much of the EU accident population as possible with the necessary explanation of discrepancies between regions. It will analyse the interactions between technology-based applications and the prioritization of the most promis-

ing package of applications as far as safety is concerned and will give guidance on the most appropriate test procedures for a selection of applications, based on real driving data (FOT's) and accident data.

Naturalistic driving

(6) DaCoTA will develop and validate a common methodology to record and analyse the behavioural and exposure data and to propose an implementation plan to setting up joint naturalistic driving observations through Europe.

This work package will result into an implementation plan how Naturalistic Driving could be used for large scale data gathering on road safety within ERSO. The implementation plan describes how and which data could be gathered by Naturalistic Driving observations additional to or instead of other data gathering methods that are currently used, based on a comparison of feasibility, reliability and cost efficiency of the different measurement methods available.

Initially, DaCoTA will examine the feasibility of designing a Naturalistic Driving study which would examine key Safety Performance Indicators developed by SafetyNet which related to driver behaviour. These included;

- Speed
- Belt use
- Alcohol
- Distraction (although this was not addressed within SafetyNet)

Appendix III: Summary of projects outside Europe

42 Institution/country: Toyota Advanced Driving/South Africa

Objectives: Driver assessment, e.g., taxi driver competition 'Brandhouse Number One Taxi Driver Campaign'. The objectives of the study were to investigate training effects (drivers should learn to check for blind spots, speed limits, viewing behaviour at junctions), and driver characteristics (obey traffic rules, proper behaviour at junctions, to act passenger friendly).

Methods: Video based in-vehicle camera device, capturing driver and scene video, also recording audio, GPS positions as well as G-forces and vehicle speed.

Driver groups: Taxi drivers, professional drivers

Variables: braking patterns, driving style, number of traffic violations.

43 Institution/country: Hubert Ebner (India) Pvt. Ltd., New Dehli, India

Objectives: Document driving test objectively by recording audio and video data and mark driving errors and offences during the driving test. Several aspects of driver characteristics will be investigated.

Methods: 2 camera Pdrive Systems provided by TTI

Driver groups: Candidates for official driving exam

Variables: Traffic violations and errors: speed, traffic offences such as improper lane keeping, touching of other vehicles in dense traffic, forgetting to honk, and exceeding certain limits of lateral and longitudinal forces.

44 Institution/country: Hong Kong school of Motoring, Hong Kong

Objectives: Learn to drive/driver assessment/company driver selection and monitoring

Methods: Four miniature video cameras are installed in strategic positions of the vehicle, recording the actions of the driver, the road scene and speed of the vehicle. After the driver, our instructor/assessor (who was sitting in-car besides the student), will go through the video and share his observation with and give recommendations to the student. The instructor will issue a Driving Assessment Form to the student at the end of the lesson.

Another application is that our Recording Vehicle will follow the 'target vehicle' and record the subject driver's driving behaviour. The video clips are analysed by a special team and a report on the observed behaviours will be formulated. The subject driver has no knowledge of being video-taped.

Variables: actions to hazards, handling or road environment and junctions, vehicle handling, use of mirrors and signals, road disciplines, speed and space control.

Appendix IV: Research fields and topics

Research field	Examples of research topics	Reference in appendix
Driver distraction and inattention	Exposure to distractions	3,19, 20,24,
	Distraction contribution to accidents/incidents	3,18,19,20,24
	Relative risks associated with distractions	3,19,20
	Population attributable risks associated with distractions	3,19,34
	Distraction and risk compensation	9
	Distraction under different environmental conditions	3
Drowsiness and fatigue	Physiological measures of driver drowsiness (e.g. eye lid closure)	26,19
	Behavioural measures of driver drowsiness (e.g. lane deviations)	19
	Frequency/exposure to drowsiness	26,19
	Drowsiness contribution to accidents/incidents	4,26
	Drowsiness among commercial vehicle drivers	4,10,21,29
	Drowsiness among team versus single commercial drivers	21
In-vehicle systems	In-vehicle safety systems and risk compensation	9,23
	In-vehicle systems and distraction	
	Pattern of use of in-vehicle systems	9,32
	Implication of use of in-vehicle systems for safety	8,34
	Testing and evaluation of in-vehicle systems (although more common in FOTs)	8, 36
Lane-change behaviour	Duration of lane-changes	13,27
	Lane-changes of different vehicles (e.g. light and heavy vehicles)	13
	Lane-changes of different drivers	27
	Signal use during lane-changes	27

Heavy vehicle-light vehicle interaction	Interaction from light vehicle perspective	17
	Interaction from heavy vehicle perspective	11
	Culpability of incidents/accidents between light and heavy vehicles	11,17
	Contributing factors of at-fault part in incidents/accidents	11,17
Driver characteristics and states	Young, novice drivers' driving behaviour and involvement in incidents/accidents	1,7,12,22,
	Route choice of young drivers	
	Young drivers and engagement in distractive activities	
	Elderly drivers' driving behaviour and involvement in incidents/accidents	
	Health conditions and accident involvement/risk	5
Applied use of naturalistic driving observation	Feedback to young novice drivers during driver training or GDL period	1,7,12,22,38,39,41
	Feedback to elderly drivers	
	Feedback to other drivers	38,40
Eco-driving	Eco-driving behaviour measures (e.g., choice of gear, maintaining steady speed, decelerate smoothly)	7,14,30
	Short-term and long-term effects of eco-driving course	7,14
Site based naturalistic studies	Driver behaviour at specific site (e.g. at a specific junction)	15
	Interaction between various types of road users (including vulnerable road users)	16
Comparison of naturalistic observation with self-report	Compare self-report of exposure to actual exposure	2
	Compare self-report of involvement in accidents with actual accidents	7
	Validation of standardized test batteries	
	Compare driving behaviour of different drivers as identified by self-report measures	19
	Compare involvement in accident of different drivers identified by self-report measures	
Environmental factors and infrastructure	Interaction between driver, vehicle and environment	19

	Driver behaviour and accident involvement under specific road and traffic situations (urban, rural, intersections, traffic volume, etc.)	37
	Engagement in secondary tasks under specific road and traffic situations	19

Appendix V: Relevant websites

PROLOGUE website:	*http://www.prologue-eu.eu/*
INTERACTION website:	*http://interaction-fp7.eu/*
2besafe website:	*http://www.2besafe.eu/*
TELEFOT website:	*http://www.telefot.eu/*
EuroFOT website:	*http://www.eurofot-ip.eu/*

More information about :

100 car study: *http://www.nhtsa.gov/*

SHRP2: *http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/Public/Blank2.aspx*

List of Abbreviations

ACC:	Adaptive cruise control
CAS:	Collision avoidance system
CO:	Confidential Deliverable
DAS:	Data acquisition system
DDWS:	Driver drowsiness warning system
FCW:	Forward collision warning
FOT:	Field operational test
GDL:	Graduate driver licensing program
HOS:	Hours of service
IVDR:	In-vehicle data recorder
KSS:	Karolinska sleepiness scale
LV/HV:	Light vehicle/heavy vehicle
L/SH drivers:	Local/short haul drivers
ND:	Naturalistic driving
OR:	Odds ratio
PAR:	Population attributable risk
PU:	Public Deliverable
QA:	Quality Assurance
RE:	Restricted Deliverable
WP:	Work Package