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Towards a large-scale European Naturalistic Driving study: final report of PROLOGUE

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Abstract

This report is the final report of the PROLOGUE project. It provides a concise overview of the main findings of the project in its aim to assess the usefulness and feasibility of a large-scale European Naturalistic Driving (ND) study. Successively, the report discusses the most important information about and characteristics of:

- The ND approach in comparison to more traditional research methods;
- Previous experiences;
- Small-scale ND studies in PROLOGUE;
- Potential application areas and potential users;
- Equipment and other technological requirements;
- Methodological considerations;
- Legal and ethical issues;
- Recommendations for a large-scale ND study.

Each section concludes with suggestions for further reading, including the references to the PROLOGUE Deliverables.

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Executive Summary

Naturalistic Driving

Naturalistic Driving (ND) studies represent the state of the art in traffic safety research and can be defined as studies undertaken to provide insight into driver behaviour during every day trips by recording details of the driver, the vehicle and the surroundings through unobtrusive data gathering equipment and without experimental control.

Typically, in an ND study passenger cars, preferably the subjects' own cars, are equipped with several small cameras and sensors. For several months to several years, these devices continuously and inconspicuously register vehicle manoeuvres (like speed, acceleration/deceleration, direction), driver behaviour (like eye, head and hand manoeuvres), and external conditions (like road, traffic and weather characteristics).

Thus, the ND approach allows us to observe and analyse the interrelationship between driver, vehicle, road and other traffic in normal situations, in conflict situations and in actual crashes. This type of information is not just useful for reducing road transport casualties, but also for reducing the environmental burden of road transport, and for reducing congestion.

ND studies are not limited to passenger cars since vans and trucks can also be studied in a naturalistic way. Similarly, motorcycles can be equipped: naturalistic riding. The specific problems of pedestrians and cyclists can be studied based on observations from the vehicle. However for this application, naturalistic site-based observations can be a useful addition.

PROLOGUE

The first ND study was performed in the US in the early 2000s and became known as the 100-car study. Very recently a new large-scale study started in the U.S. involving 2,000 cars. The PROLOGUE project aimed to assess the feasibility and usefulness of a large-scale Naturalistic Driving study in Europe and to formulate recommendations for such a large-scale study.

The nine partners of the PROLOGUE consortium conducted various activities to reach that aim, such as literature reviews and analyses, questionnaires, as well as five small-scale practical field trials. Since getting the support and involvement of potential stakeholders was an important goal of the project, a wide variety of dissemination activities took place, including two international and six regional workshops. The current report is the final report of this project, providing a concise overview of its main findings.

Previous ND studies

When looking into the literature, it appears that the vast majority of ND research performed so far focused on road safety. Topics that received particular attention were distraction and fatigue as well as the applied use of naturalistic driving data, e.g. in driver training. The use and (safety) effects of in-vehicle information systems and in-vehicle warning systems are generally the focus of what is called Field Operational Tests (FOTs) and these tend to apply ND-like methods. Non-safety related transport topics, such as eco-driving and congestion were studied substantially less frequently.

PROLOGUE's small-scale field trials

Within PROLOGUE, five small-scaled field trials were conducted. One of the aims of the trials was to get a better feeling of the technological aspects of ND research and the strengths and weaknesses of various approaches. Another aim was to give an impression of the wide range of application areas of ND research. For this reason the five trials differed substantially with regard to technological aspects such as type of equipment, methodology, analysis methods etc. Some of the trials applied a pure naturalistic approach, i.e. just having the participants drive for a period of time and subsequently analyzing the data; other field trials focused on ND research and ND data as a tool to evaluate a particular intervention, e.g. video feedback to learner drivers or monitoring the use and effects of in-vehicle systems. This latter application is very similar to an FOT with an ND approach.

Research questions

ND research can help to answer a very broad range of research questions. As part of the US SHRP2 study a very comprehensive list of research questions for an ND study was developed, consisting of a total of more than 400 questions. With this list as a source of referencing, PROLOGUE took a somewhat different approach to identify the potential research questions. Here, the research questions were defined in terms of combinations of (1) categories of driving behaviour and driver states and (2) conditions under which driving behaviour may be observed. This resulted in a two dimensional matrix that can be used as a frame for structuring research topics in a general way and, from there, for specifying and prioritizing the research questions. The specific research questions are supposed to comprise observing driver behaviour not only in relation to road safety, but also in relation to traffic management and environmentally friendly driving (eco-driving).

Potential users and their interests

As a starting point, PROLOGUE considered ND research potentially interesting for a wide variety of transport-related professionals, including not only road transport researchers, but also car industry, insurance companies, driver training and certification organisations, police, road authorities, and policymakers. To get a better feeling of the exact interests of these stakeholders, a User Forum was set up, and two international and six national/regional work-shops were organized. In addition, two small-scale surveys were performed; one among the User Forum members and another among work-shop participants.

In general, the workshops and the surveys demonstrated that there is indeed much interest in ND research and its potential to contribute to new, important knowledge. The main interest of the potential users of ND knowledge appeared to be in road safety topics, and more precisely in risk-taking behaviour, pre-crash behaviour, crash avoidance behaviour and driver conditions. Whereas so far ND research almost exclusively focuses on passenger cars and trucks, it was stressed repeatedly that ND research would also need to focus on the safety of pedestrians and cyclists, as well as on the safety of powered two-wheelers.

Applying ND data to the environmental area there was an interest in the relationship between, on the one hand, the general characteristics of different vehicle types in different driving conditions, operated by people with different driving styles, and, on the other hand, the exhaust emissions and fuel consumption.

Technical requirements

The ND approach has become possible thanks to technological developments in data collection, data storage capacities, data-mining, image processing, with tools that become increasingly smaller, less obtrusive and less expensive. At the same time, the many technical options require careful consideration to decide on the most suitable and reliable data acquisition system (DAS) and data handling, to ensure successful outputs. Within PROLOGUE, various aspects of the technical requirements have been studied. The experiences of European FOTs and the ND experiences in the U.S. were important sources of information.

Though some basic data can be gathered by relatively simple equipment such as provided by the CAN-bus or a Smartphone type of apparatus, for many research questions video data would be indispensable, in particular for recording the road and traffic situation in front of the car and of the driver. In many instances, additional video data of the rear and the side of the car would substantially aid the interpretation of, for example, critical events or near misses. For very specific questions, mainly those related to distraction and inattention, additional eye tracking equipment would be needed.

Subsequently, rigorous data uploading and back-up procedures are essential to minimise data loss. This also includes data verification and validation. Careful consideration should be given to the storage capacity of the database in advance to ensure that all relevant data can be stored throughout the course of the study. For example, the large-scale SHRP2 ND study in the U.S. is expected to result in 1 petabyte of data, i.e. one million gigabytes. Therefore, some sort of automated procedure for analysing the data and for identifying important events in the data is essential, minimizing both false positives and false negatives.

Methodological and legal considerations

When conducting an ND study, there are also various methodological considerations to make in order to ensure that it is a scientifically sound study resulting in reliable and valid conclusions. Important topics to consider are selection of subjects, definition of variables, study design, and data analysis. The exact research questions determine the desired composition of the participants, the vehicles included and the variables studied. In case of an overall data collection effort, the participants must represent the general driver population and the most popular vehicles must be included. Since participation in an ND study is voluntary, there is a potential 'self-selection' bias. Regarding vehicle selection it is important to realize that newer cars have more or different information available through the CAN bus or OBD than older cars.

Legal and ethical issues need to be considered relating to, for example, obtaining the required permissions, ensuring that the vehicles are safe to operate on public roads, going through any required ethical and human subject review procedures, getting participants' informed consent, complying with data protection and privacy laws, insuring the vehicles, and insuring the project workers for liability. Therefore, it is wise to obtain legal advice at an early stage of the project. In this respect it must be noticed that regulations and laws vary from country to country. Furthermore, it is of crucial importance that the data are protected, that privacy is ensured and that participants have the right to withdraw from the study and/or erase data at any given time.

Recommendations: PROLOGUE's 11

The findings and experiences in PROLOGUE finally resulted in a set of recommendations for a large-scale study covering the research questions, the potential users, methodology and equipment. The most important general recommendations have been summarized in eleven items, PROLOGUE's 11:

1. The European ND study should include pedestrians and (powered) two-wheelers (VRUs), and trucks, in addition to cars thus distinguishing it from the U.S. studies
2. An integrated data acquisition system is recommended because use of different technologies and vendors within the same project creates validation and data compatibility issues that lengthen the study and make it more expensive.
3. Difficulties associated with recruiting drivers, as experienced in the SHRP2 project, should be taken into consideration when planning the large-scale study, and should be addressed in the design and the timetable of the study.
4. In part of the study site-based and in-vehicle observations should be combined.
5. Some specific research questions should be stated, and the design should be geared to answering them. An example of a design adaptation to specific research questions is over-sampling of certain groups, like young drivers, old drivers, or new vehicles.
6. Automatic recording of behaviour should be supplemented by driver interviews e.g. to investigate look-but-did-not-see incidents with powered two-wheelers. The ND database should also be enriched by adding other driver background data like sensation seeking, Driver Behaviour Questionnaire, and past violations and crashes.
7. Emissions and on-line fuel consumption should be recorded for analysing eco-driving and environmental effects.
8. Route and lane preferences and their relationship to background variables should be observed in order to provide relevant data for traffic management purposes.
9. Inputs and/or insights from different stakeholders should be used to identify specific research questions.
10. Cultural differences in driving patterns should be investigated; this requires data about type, number and locations for different observation sites.
11. Some aspects of the data collection measures should be harmonized with those of SHRP2 and other large-scale naturalistic driving databases for the purpose of comparing European data with data from the U.S. and elsewhere and also for combining databases to get larger samples for analysing crash risk.

1 Introduction

1.1 The PROLOGUE project

The current report is a summary report of the main findings of the PROLOGUE project. PROLOGUE was a research project in the seventh Framework Programme for research and technological development of the European Commission, and it was co-financed by the Commission's Directorate-General for Research. The main aim of PROLOGUE was to assess the feasibility and usefulness of a large-scale European Naturalistic Driving study and to formulate recommendations for such a large-scale study.

PROLOGUE, an acronym for PROMoting real Life Observations for Gaining Understanding of road user behaviour in Europe, was a two-year project running from August 2009 until July 2011. The research consortium consisted of nine partner institutes, and was coordinated by SWOV Institute for Road Safety Research (*Table 1.1*).

Table 1.1 The partner institutes of the PROLOGUE consortium

PROLOGUE Consortium	Country
SWOV Institute for Road Safety Research (Coordinator)	The Netherlands
Centre for Research and Technology Hellas CERTH-HIT	Greece
KfV Austrian Road Safety Board	Austria
Transport Safety Research Centre, Loughborough University	United Kingdom
Or Yarok	Israel
TNO Defence, Security and Safety, BU Human Factors	The Netherlands
TØI Institute for Transport Economics	Norway
Training & Testing International TTI	Austria
SINTEC-INTRAS, Universitat de València	Spain

First and foremost, PROLOGUE aimed to explore, test and promote the possibilities of Naturalistic Driving research for road safety. In addition, but in less detail, PROLOGUE looked at the possibilities of Naturalistic Driving research to provide useful knowledge for environmental and traffic management purposes. The project mainly focused on stakeholders with a direct or indirect interest in road transport including car industry, insurance companies, police, road user umbrella organisations, driver training and certification organisations, road authorities, and national and regional governments.

1.2 What is a Naturalistic Driving?

Naturalistic Driving methods represent the state of the art in traffic safety research and they are intended to be used to gather data that represent the behaviour of the population of drivers in its basic state. A Naturalistic Driving (ND) study can be defined as:

A study undertaken to provide insight into driver behaviour during every day trips by recording details of the driver, the vehicle and the surroundings through unobtrusive data gathering equipment and without experimental control.

Key features of ND studies include:

- Drivers use their own vehicles in their normal manner.
- The data gathered covers the driver, vehicle and surrounding road environment.
- The instrumentation is unobtrusive and drivers cease to be aware after a short period.
- There are no observers present in the vehicle.
- Data is recorded continuously during the driving process.

Ideally, a large-scale ND study would include a large number of fully equipped vehicles for a considerable period of time; the collected data being stored in a large database that subsequently is exploited to answer a wide variety of research questions. It is also possible to focus the ND research effort at a limited number of specific research questions, with the equipment and sample specifically tailored to those questions.

The first major ND study was conducted in the US by Dingus et al.¹ who instrumented 100 cars owned by young drivers and gathered data over a 12-month period. During this time the vehicles were driven over 3,000,000 km with a total of 43,000 hours exposure involving 67 crashes and 761 near-misses. The instrumentation included video and location data with some vehicle system data which, for example, identified distraction as being much more frequently related to critical incidents than had previously been expected. This 100-car study is now being continued in the US SHRP2 project (see *Section 2.1* below).



Figure 1.1 Camera set-up (left) and the recorded video data (right) in an ND study
(Source: www.prologue-eu.eu)

¹ Dingus, T. A., Klauer, S.G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., Perez, M. A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z. R., Jermeland, J., and Knippling, R.R. (2002) *Phase II – Results of the 100-Car Field Experiment*. NHTSA report DOT HS 809 593. Washington, US.

The ND approach has become possible thanks to technological developments in data collection, data storage capacities, data-mining, image processing, with tools that become increasingly smaller, less obtrusive and less expensive.

1.3 Other areas and other road users

The ND approach allows for observing and analysing the interrelationship between driver, vehicle, road and other traffic in normal situations, in conflict situations and in actual crashes. So far ND has been mainly used from a road safety perspective. However, in addition to road safety, ND research is expected to provide valuable knowledge about human behaviour in relation to environmental issues such as exhaust emissions and fuel consumption, as well as to aspects related to traffic circulation, road capacity and traffic management. The basic idea is that the ND approach validates existing knowledge and generates new knowledge where traditional methods fail to give adequate answers. Furthermore, ND data can be used to validate other research methods.

Obviously, not only drivers of passenger cars, but also those of vans and trucks can be studied in a naturalistic way. Similarly, motorcycles can be equipped: naturalistic riding. The specific problems of pedestrians and cyclists can be studied based on observations from the vehicle and in this case naturalistic site-based observations are considered to be a useful addition (*Section 3.4*).



Figure 1.2 Also motorcycles can be equipped for collecting ND data
(Source: PROLOGUE Newsletter 2, August 2010)

1.4 Naturalistic Driving in relation to Field Operational Tests

An approach related to ND is the Field Operational Test (FOT). An FOT is defined as²:

A study undertaken to evaluate a function, or functions, under normal operating conditions in environments typically encountered by the host vehicle(s) using quasi-experimental methods.

² FESTA Consortium (2008) FESTA handbook version 2. D6.4 of the Field opErational teSt supporT Action (FESTA).

The overall purpose of FOTs is also well summarised in the first annual report of the U.S. Automotive Collision Avoidance System (ACAS) programme report³, stating that an FOT:

[.....] provides an ideal opportunity for the Government, industry, and ITS community to gain a more thorough understanding of the requirements, functions and societal impact of a technology. Additionally, any potential adverse operational and safety-related issues could be identified, analyzed, and addressed while the technology is still in the early stages of product development“.

In other words, one of the main aims of an FOT is to gain insight into how and when the targeted drivers use vehicle technologies and how these affect their traffic behaviour. The test in real life conditions is often performed as an ND study, i.e. by fitting several unobtrusive registration equipments to the vehicle, and monitoring driver behaviour and driving conditions continuously for some time, comparing the situation before and after the function of interest is available. So, ND is a research method that can be applied in FOTs to test the use and effects of in-vehicle technologies.

Figure 1.3 A vehicle in a euroFOT study on In-Vehicle Systems
(Source: www.volvogroup.com)

1.5 Limitations of traditional research methods

So far, the most common methods to study road safety were simulator studies, instrumented car studies, self-report studies, analyses of crash statistics, and increasingly also in-depth crash investigation. These methods have greatly contributed to the understanding of road user behaviour and other crash-related factors. However, they also have several limitations. For example, results from driving simulator studies may not always be easily transferred to real traffic, since both the traffic environment and the vehicle characteristics are only proxies of reality. This is especially true in the more simple, and static-based simulators. In instrumented car studies subjects drive in real traffic but in a special, highly equipped car with, normally, an experimenter onboard. This will make subjects aware of the fact that they participate in an experiment and this may affect driving behaviour. In both simulator studies and instrumented car research, it will hardly be possible to observe real crashes or near crashes. The results of self-reports may be biased by socially desirable responses as well as by perceptual and memory limitations. Crash data is objective, but it generally insufficiently explains how and why a crash occurred. Moreover, due to underreporting, the documentation of in particular non-fatal crashes is far from complete. In-depth crash analyses provide valuable additional information about the how and why of a crash, but based on information collected after the crash, including post-hoc self-reports and witness reports.

1.6 Advantages of an ND study

Compared to these traditional road safety research methods, ND has many advantages. First, it offers much wider perspectives in understanding normal traffic behaviour in normal everyday traffic situations. Participants are not involved in an experiment;

³ Automotive Collision Avoidance Systems Programme (ACAS) - Final Report to the US Department of Transport, 2000, report number DOT HS 809 080 http://www.nhtsa.gov/people/injury/research/pub/acas/ACAS_index.htm

there is no experimenter present, there are no experimental interventions or aims that participants can guess and act for. Furthermore, there is the possibility to observe conflicts, near crashes or even actual crashes in real time without potential biases of post-hoc reports. As such an ND study can contribute to clarifying the prevalence of, for example, fatigue and distraction amongst drivers and the related crash risk, to clarifying the interaction between road and traffic conditions and road user behaviour, to understanding the interaction between car drivers and vulnerable road users in different circumstances, to specifying the relationship between driving style and vehicle emissions and fuel consumption, and many other aspects of traffic participation that are difficult to study by means of traditional research.

1.7 Limitations of an ND study

Although for many research questions the advantages of an ND approach outweigh the disadvantages, a few limitations of the ND approach must be taken into account. A first and important disadvantage is that, by definition, in an ND study there is no experimental control of the various variables that potentially affect the behaviour of the road user. This means that ND data results in correlation between particular variables and road user behaviour, but not in unambiguous causal relationships.

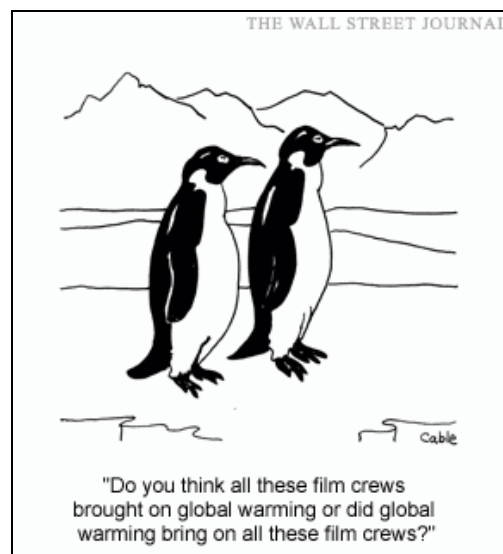


Figure 1.4 What causes what? An ND study does not prove causal relationships
(Source: filippagnoli.wordpress.com)

Second, it is generally assumed that in an ND study drivers behave as they normally do, because after a while they forget that they participate in a study and that they are being observed all the time. There are indeed strong indications from US experience that this is what actually happens, but so far, strict scientific proof is lacking.

A third related issue is that drivers in the study sample participate on a voluntary basis. Therefore, it cannot be ruled out that there is a self-selection bias and that the volunteers differ in relevant aspects from non-participants. Hence, the observed behaviour may not always be representative of the whole population. However, the direction and

the approximate size of such a bias can be established and taken into account by using carefully designed background questionnaires.

A last practical disadvantage to mention here is that a full-scale ND study, i.e. including collection of various video data, is relatively expensive and time-consuming. To make an ND study cost-effective, it is important to identify the research questions that are relevant for the various stakeholders and to address as many of these research questions as possible in one ND study. For each research question it has to be determined whether such a full-scale ND study is indeed the most appropriate approach or whether a less extensive ND study, or an alternative research approach, is a workable alternative.

1.8 Other applications of ND research

In its purest form, an ND study does not contain experimental interferences. Drivers just drive their ordinary trips for a considerable amount of time. During that period, data is collected and stored, and subsequently made available for analysis to get an answer to the various research questions. However, it is also possible to use the ND approach in some sort of experimental setting. *Section 1.4* already presented the Field Operational Tests, in which, in general, data are collected before and after the implementation of a specific function or technology, to see how this affects traffic behaviour. Similarly, it is possible to use the ND methodology to evaluate, for example, the effects of various driver training methods or training modules on the behaviour of learner and in-experienced drivers. It is also possible to use the collected ND data to give personalized feedback about the driving behaviour, linked to, for example, a reward programme.

1.9 Aim and setup of this report

The aim of the current report is to provide a concise and accessible overview of the main findings of the PROLOGUE project. It is certainly not meant to be exhaustive, but rather to give a flavour of the various aspects that play a role when defining the usefulness and feasibility of a large-scale ND study in Europe. For a detailed overview of the findings we refer to the individual PROLOGUE Deliverables as listed in *Appendix I*.

Chapter 2 presents some main previous experiences with ND research and FOTs and *Chapter 3* reports about the experiences during a series of small-scale field trials within PROLOGUE itself. Subsequently, *Chapter 4* describes the potential application areas for an ND study and the potential users of ND knowledge as well as their interests. The next chapters successively discuss some of the technical (*Chapter 5*), methodological (*Chapter 6*) and legal/ethical considerations (*Chapter 7*) based on the literature and the experiences. Finally, *Chapter 8* provides the main concluding recommendations for a large-scale naturalistic study.

2 Previous and current Naturalistic Driving studies

During the last decade, Naturalistic Driving (ND) studies have won ground in road safety research. The first experiences originate from the United States in what has become known as the 100-car Naturalistic Driving study and which resulted in the current much larger naturalistic study in the second Strategic Highway Research Program (SHRP2). These two studies will be briefly presented first. Also various other studies applied the ND method, often looking at specific research topics, mostly related to road safety, incidentally also at environmental issues or traffic management. As an illustration this chapter presents some examples of these studies as well.

2.1 Experiences in the United States

The first ND study was performed in the US in the early 2000s. In this study, which has become known as the 100-car study, one hundred young drivers who commuted on a regular basis in the Northern Virginia/Washington D.C metropolitan area participated. Approximately three quarters of these drivers drove their own car, whereas approximately one quarter drove a leased car. Data was collected over a 12-month period. Drivers using their own car received \$125 per month and a bonus at the end of the study, whereas drivers using a leased car received free use of the car and a bonus at the end.

All vehicles were instrumented with a data acquisition system (DAS) engineered by Virginia Tech Transportation Institute (VTTI) as depicted in *Figure 2.1*.

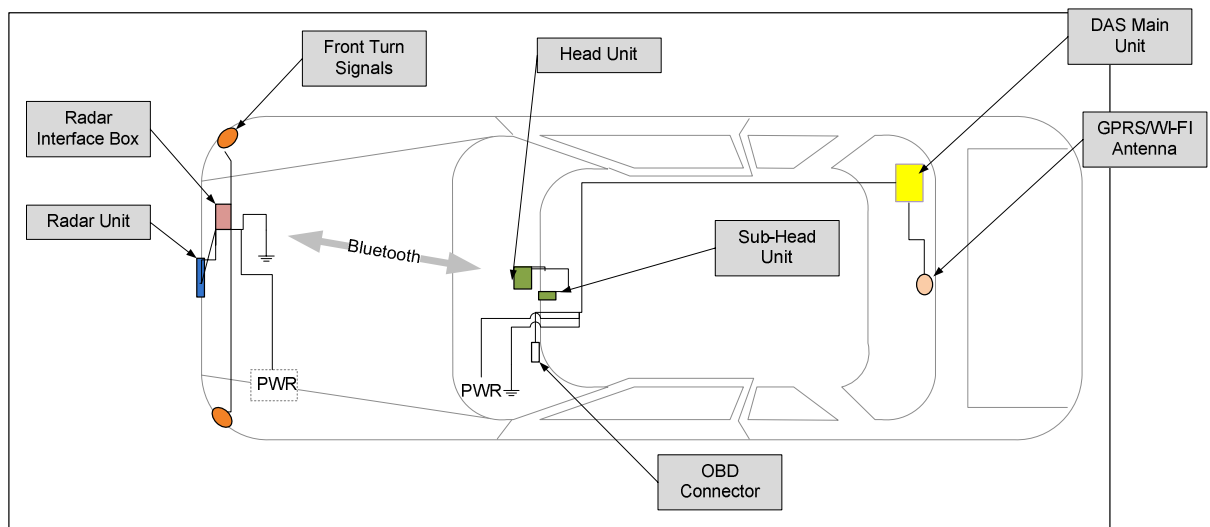


Figure 2.1 The Data Acquisition System (DAS) in the 100-car ND study in the United States (Source: www.trb.org).

Furthermore, five video cameras were installed, monitoring

- driver's face and driver side of the vehicle;
- driver's hands and surrounding areas;
- the passenger side of the vehicle;
- external forward view;
- external rear view.

The final data set included information about a total of 2,000,000 vehicle miles, and, per vehicle, 43,000 hours of data gathered over a period of 12 months. The study resulted in very detailed information about driver behaviour, environment, driving context and other factors that were associated with critical incidents, near crashes and crashes. The study provided information about 67 actual crashes, 761 near-crashes and 8,295 incidents.

The 100-car study was meant as a pilot for a much larger ND study in the United States. This large-scale study is indeed realized as part of the second Strategic Highway Research Program (SHRP2). In 2010 the first cars of the intended 2,000 cars were instrumented. Participants will drive their instrumented car for 1 or 2 years, resulting in data from over 3,000 drivers, well spread over different age groups. The main objective of this large-scale study is to address the relationship between driver performance and behaviour on the one hand, and traffic safety on the other. More specifically the objective is to investigate how drivers interact with and adapt to the vehicle, traffic environment, roadway characteristics etc, and to estimate differences in crash risk associated with this. The study uses the same DAS as in the 100-car Study (*Figure 2.1*), with four cameras (*Figure 2.2*).



Figure 2.2 The four video camera views in the large-scale SHRP2 study (Source: www.trb.org)

2.2 A few application areas of previous ND research

The objective of both the 100-car study and the large-scale SHRP2 study in the U.S. related to road safety. When looking into the literature, it appears that this is the case for the vast majority of other ND research that has been performed so far. Within the area of road safety, the following topics received most attention:

- Driver distraction and inattention
- Drowsiness and fatigue
- Other driver characteristics and states
- In-vehicle systems
- Lane change behaviour

- Interactions between heavy and light vehicles
- Applied use of naturalistic driving data, e.g. in driver training and graduated driver licensing programmes

Non-safety related transport topics, such as eco-driving and traffic flow were studied substantially less frequently. The next sections describe just a few examples of ND studies in these areas.

2.2.1 Driver characteristics and states

The effects of driver characteristics and states, such as fatigue and distraction, on behaviour and crash risk belong to the most obvious application areas of ND research. For example, driver distraction was of particular interest in the 100-car study in the U.S.. Just as an illustration, one of the findings there was that in almost 78% of all crashes and in 65% of all near-crashes, the driver had not looked in the direction of the arising conflict preceding the crash or near-crash. Having the eyes off the road for more than two seconds appeared to significantly increase crash and near-crash risk. Performing complex secondary tasks while driving increased the (near-)crash risk by three times and moderate secondary tasks by two times⁴.

In another ND study, also in the U.S., it was found that for truck drivers the behaviour associated with the highest risk was when the drivers' eyes were drawn away from the road in front of them. The highest risk was found for texting while driving. Drivers who did so were 23 times more likely to be involved in a safety-critical event than if they were not texting. Many other complex tasks also increased risk substantially. As an illustration, *Table 2.1* presents just a few of the results of this study⁵.

Table 2.1 Likelihood of a safety-critical event while performing non-driving related tasks (Source: Olson et al., 2009)

	Odds ratio (Best estimate of the increased risk)	95% Confidence Interval (With 95% certainty between)
Text on cell phone	23.2	9.7 - 55.7
Write on pad/notebook	9.0	4.7 - 17.1
Look at map	7.0	4.6 - 10.7
Dial cell phone	5.9	4.6 - 7.7
Reach for object in vehicle	3.1	2.8 - 3.5
Talk or listen to CB radio	0.6	0.4 - 0.8

2.2.2 Interactions between road users

Another potential application area is the interaction between road users, e.g. the interaction between drivers of different vehicle types. In the 100-car study, the interaction

⁴ Dingus 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.

⁵ Olson et al. (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.

between light vehicles (passenger cars) and heavy vehicles was investigated from the perspective of the light vehicle drivers⁶. In another study, also in the U.S., these interactions were studied from the heavy vehicle perspective⁷. Results from both studies indicate that in a majority of the incidents between light and heavy vehicles, the light-vehicle drivers were at fault. In the heavy-vehicle perspective study 78% of the incidents were initiated by light-vehicle drivers and in the light-vehicle perspective study this was 64%. *Table 2.2* shows the top 3 causes of, respectively, the light vehicle at-fault and the heavy vehicle at-fault incidents.

Table 2.2 The three most frequent incident types for 'light vehicle at-fault' and 'heavy vehicle at-fault' incidents (Source: Hanowski et al., 2006)

	Percentage of light vehicle at-fault incidents (N = 138)
Late braking for stopped/stopping traffic	41.3% (N=57)
Lane change without sufficient gap	21.7% (N=30)
Aborted lane change	8.0% (N=11)
	Percentage of heavy vehicle at-fault incidents (N = 79)
Lane change without sufficient gap	26.6% (N=21)
Lateral deviation of through vehicle	21.5% (N=17)
Left turn without clearance	13.9% (N=11)

2.2.3 High risk groups

Yet another application area of ND research is the behaviour of road user groups that have an elevated crash risk, e.g. young drivers. In Israel, for example, it was found that young drivers generate more events (i.e. risky behaviours) per hour than their parents. In particular, they generate 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 drivers⁸.

2.2.4 Eco-driving

So far, only a few naturalistic studies have been performed in the area of eco-driving or green driving even though there are various relevant research questions in this area that could be answered by means of an ND approach (see *Chapter 4*). One study, for example, focused on the effect of driving patterns on the emissions and fuel consump-

⁶ Hanowski et al. (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.

⁷ Hanowski et al. (2007) *A descriptive analysis of light vehicle-heavy vehicle interactions using in situ driving data*. *Accident Analysis and Prevention*, 39, 169-179.

⁸ Lotan & Toledo (2005). *Evaluating the safety implications and benefits of an in-vehicle data recorder to young drivers*. Proceedings of the third international driving symposium on human factors in driver assessment, training and vehicle design. Transport Research Board, Rockport, Maine.

tion of cars. Nine of the driving pattern factors appeared to be relevant: four were associated with aspects of power demand and acceleration; three were related to gear changing; and two to specific speed intervals⁹.

2.3 Current ND and FOT projects in Europe

Currently, several ND projects and FOTs with an ND approach are being performed in Europe. Without the intention to be complete, these include:

- INTERACTION: Driver interaction with common in-vehicle technologies such as navigation systems and mobile phones - <http://interaction-fp7.eu/> (EU)
- 2-BE-SAFE: Enhancing motorcycle safety - <http://www.2besafe.eu/> (EU)
- DaCoTA: Assessing the feasibility of ND for monitoring safety performance indicators and exposure – <http://www.dacota-project.eu/> (EU)
- SeMiFOT: Development of the Naturalistic Field Operational Test (FOT) method into a powerful tool in traffic safety research - <https://www.chalmers.se/safer/EN/projects/traffic-safety-analysis/semifot> (Sweden/Michigan)
- AOS: The effects of anti-crash system in HGV's related to safety and efficiency - <http://www.fileproof.nl/favicon.ico> (Netherlands)
- EuroFOT: Impacts of Intelligent vehicle systems on safety, efficiency, and on the environment - <http://www.eurofot-ip.eu/> (EU)
- TeleFOT: Impacts of aftermarket and nomadic devices in vehicles on the driving task - <http://www.telefot.eu/> (EU)
- FOT-Net: Networking platform for anyone interested in Field Operational Tests, their set-up and their results - <http://www.fot-net.eu/> (EU)

2.4 Further reading

Backer-Grøndahl, A., Phillips, R., Sagberg, F., Toulou, K., Gatscha, M. (2009). *Naturalistic driving observation: Topics and applications of previous and current naturalistic studies*. PROLOGUE Deliverable D1.1. TØI Institute of Transport Economics, Oslo, Norway.

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.

SWOV (2010) *Naturalistic driving: observing everyday driving behaviour*. SWOV Factsheet, version October 2010. SWOV, Leidschendam.

⁹ Ericsson (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.

3 Some small-scale field trials within PROLOGUE

Within the PROLOGUE project itself a series of five small-scale field trials were performed, which were specifically meant to

- Explore the potential and get a better feeling of the technological aspects of Naturalistic Driving research, and the strengths and weaknesses of various approaches.
- Illustrate the potential usefulness of naturalistic observations for various aspects of road safety.

The five field trials were conducted in Israel, Austria, the Netherlands, Spain and Greece. The trials varied in a number of aspects, such as the technology used, type and number of cars involved, research questions addressed, target populations, samples and sampling strategies, data handling and storage, data reduction techniques and data analysis. From the technology point of view, all field trials included a technological system measuring basic g-force based driving parameters. Beyond this, the various technological systems varied substantially, ranging from simple accelerometers to fully equipped cars. This diversity in experiences contributed to the identification of aspects to be considered in a subsequent large-scale ND study. Moreover, the trials provide an illustration of the type of information that ND research can provide. It must be noted that in all of the trials the samples were too small to allow for scientifically founded conclusions. The trials do, however, provide useful exemplary information about both the type of research questions that can be studied and the possibilities and limitations of different types of ND-like study designs.

Table 3.1 summarizes the main elements of each of the five field trials where the rows correspond to the field trials and their specific area of interest, and the columns to the main research issues addressed. In the subsequent sections, each of the five field trials is briefly discussed.

Table 3.1 Overview of the main elements of the PROLOGUE field trials

	Data collection and storage	Data reduction & interpretation	System integration	Relation ND data & self reports	Evaluation of interventions	Area of interest
Israel (IL)	x	x	x	x	x	Novice drivers
Austria (AT)	x	x		x	x	Driver training
Netherlands (NL)	x	x	x			Cyclists
Spain (ES)	x	x				In-vehicle information systems
Greece (GR)	x	x		x	x	Active safety technology

3.1 Novice and experienced drivers' behaviour

Novice and experienced drivers' behaviour was studied in Israel in a few sub-trials. All sub-trials used a data acquisition system that was based on G-forces: the GreenRoad (GR) system. One sub-trial additionally used a system with event-triggered video: the MobilEye (ME) system.

3.1.1 Integration of G-based and video-based event-triggered information

The first sub-trial compared the G-based GR system and the event-triggered video-based ME system and their ability to generate complementary knowledge about driving behaviour. The main aim was to evaluate the capabilities and potential of the two technologies for monitoring driving behaviour and to provide an initial understanding of the methods that may be used to analyse the complementary data that these systems provide. Specifically, the interest was in the similarities and differences between the data provided by the two technologies. To what extent the data collected by the systems is similar or complementary in understanding driving behaviour and risk is important in the context of determining acceptable levels of data collection, taking into account the costs of additional measurements.

For this sub-trial the ME system that was originally designed as a warning system for close following (*Figure 3.1*), forward collisions and lane departures, was reconstructed to allow for recording, transmitting and storing data. The two systems were integrated as much as possible, based on timestamps and GPS data. Ten cars were equipped with both systems and these were driven by experienced drivers for a period of just over two months.

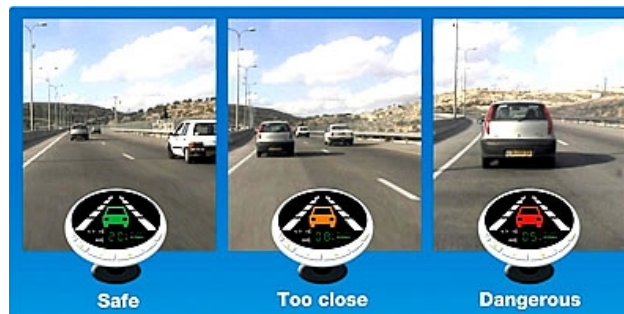


Figure 3.1 The close following warning function of the Mobile Eye system

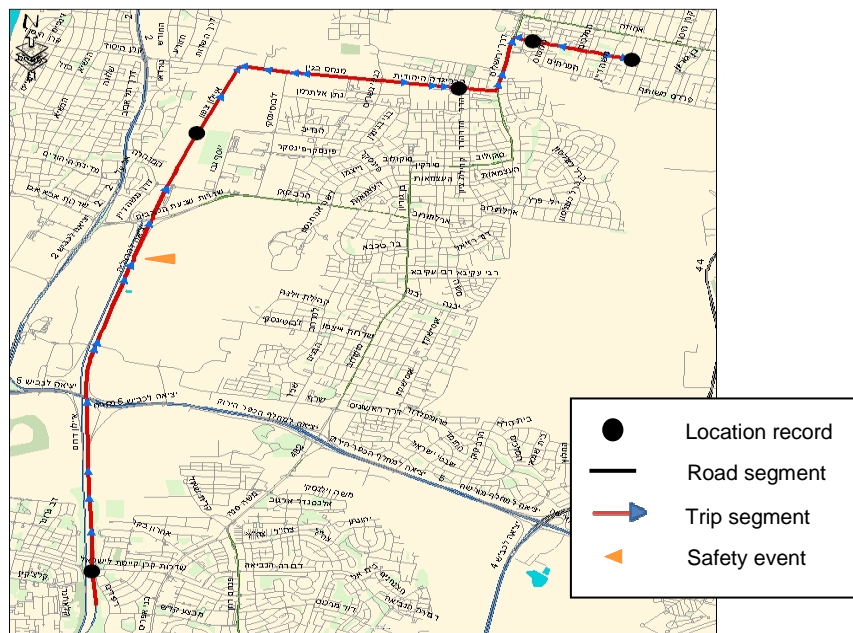
The results obtained showed much higher event rates of the ME system compared to the GR system. This finding can be partially explained by the threshold for triggering the ME events. Comparison of the two systems revealed interesting correlations between events, for example between forward collision warnings as identified by the ME system, and braking and turning events identified by the GR system.

This sub-trial also addressed the issue of proxies for near-crashes based on the two systems' event-triggered events. It was found that the severe events identified by the GR system can be considered as good proxies for near crashes, although there may be too few of them.

The overall conclusion of this sub-trial was that it is possible to integrate two different in-vehicle systems and that this results in a comprehensive data set on drivers' behaviour. It appeared that the various variables measured by the two systems are complementary, and that when put together they provide a better picture of overall drivers' behaviour than would have been possible by either one of the systems on its own.

3.1.2 Behaviour of novice drivers and their parents at different locations

The main aim of this trial was to develop a digital map-matching tool that was able to visualize the recorded behaviour of novice drivers and their parents and link it to the exact location in the road network. This map-matching tool would, for example, make it possible to get a quick view of where in the road network safety-related events or speed violations take place, and whether different groups differ in this respect. Additionally, the map matching tool enables normalisation of the event rates according to overall exposure.



Exposure layer

Uid	TripID	Segment	TravDir	Exit Time	Speed	Length	From%	To%	Sequence
17	1691971	223100	1	21/12/2007 13:02	49	290	0	100	17
18	1691971	223099	1	21/12/2007 13:02	49	75	0	100	18
19	1691971	128229	1	21/12/2007 13:02	49	76	0	23	19

Event layer

Uid	EventType	RunDist	EventDate	TravDir
19	3	23	13:02 21/12/2007	1
20	7	98	13:27 21/12/2007	1-

Figure 3.2 Illustration of a map-matching tool outputs

To illustrate its usefulness, the data from a previous study of 87 novice drivers and their parents was reanalyzed and linked to the GPS locations as processed by the newly developed map-matching tool. This way, the road sections where the events took place were identified. As shown in *Figure 3.3* and just as an example, it was found that novice drivers were more likely to exceed the speed limit on non-urban main roads and urban motorways, whereas parents had more speeding events on non-urban motorways.

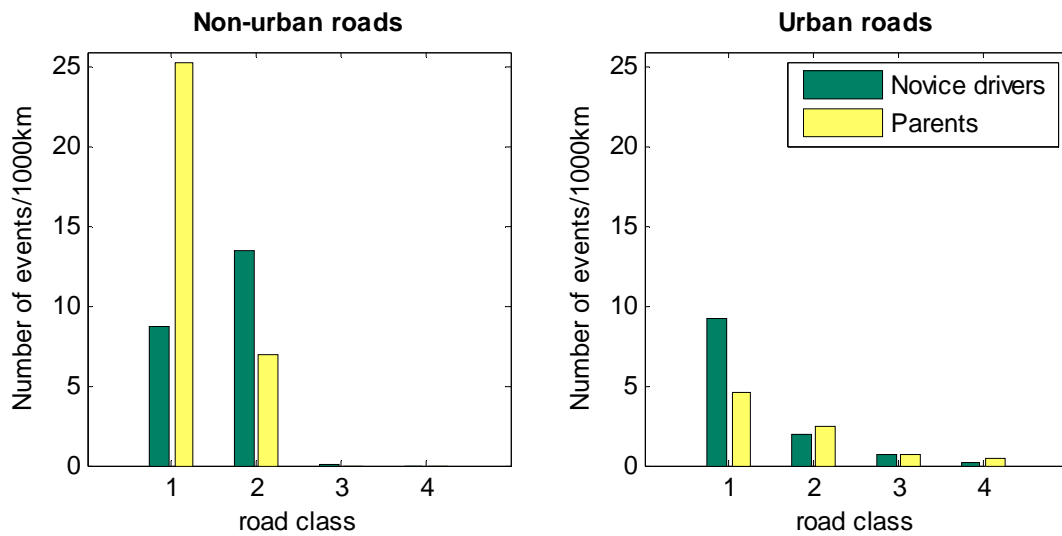


Figure 3.3 Spatial distribution of speeding events

In conclusion, the map-matching tool that was developed and implemented in this sub-trial appeared to fulfil the expectations and allowed for useful analyses. For example, the analysis performed revealed differences in exposure and event rates of young drivers and their parents according to the road type they were driving.

3.1.3 Behaviour of young drivers after a few years experience

In the third Israeli sub-trial the ND approach was applied to analyze the behaviour of young drivers 2 to 4 years after they had received their driving licence. Again the G-based GR technology was applied. The behaviour was compared with the behaviour of the same young drivers immediately after licensing, a few years before. A total of 32 young drivers participated in the current follow-up study, i.e. around 40% of the original sample. When looking at the safety related events, there was no significant difference between the event rate immediately after licensing and 2 to 4 years later.

This sub-trial was also meant to study the relationship between observed behaviour and self-reported behaviour. This comparison was based on data from 14 young drivers and it was found that there were substantial differences between the two data sources, both with respect to information about exposure, i.e. number of trips, length, time, etc and with respect to information about the safety level of their behaviour. It was found that 6 out of the 14 subjects perceived themselves as safer drivers than they were according to GR observations, 7 classified themselves similarly to GR observations, and one young driver reported to be a less safe driver than the GR data suggested.

Based on this sub-trial it was concluded that longitudinal ND studies are feasible and interesting. However, the lack of willingness to participate in an ND study a second time might bias the sample even more than during a first study.

3.1.4 Driving patterns of young drivers and their social environment

The last Israeli sub-trial focused on the effect of the social environment of young drivers on their exposure and safety level, all measured by the GR system. The sample consisted of 11 young drivers who all lived in the same community. All participants knew each other and most of them attended the same class of the senior high school year.

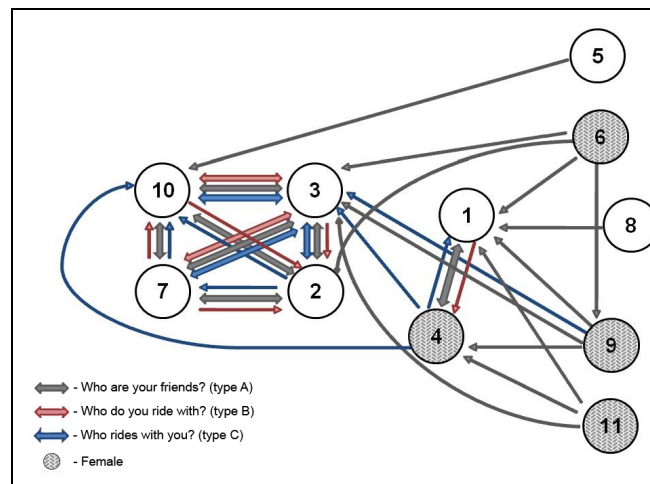


Figure 3.4 Social network of the 11 participants for three types of relations

In addition to analysing the group's driving patterns, a social network based on friendships and shared driving was created. No driving similarities were found within the small sub-groups of friendships and shared rides; however, the driving behaviour of the two outliers of the group (the "best" and "worst" drivers in terms of safety scores) revealed that the best driver was also the most "popular" person in the group, whereas the worst driver was the least popular person in the group. This finding can contribute to understanding the good driving norms of the group.

Overall, the study showed the potential of using social network mapping in combination with naturalistic data to better understand driving behaviour.

3.2 The effects of video-based feedback during driver training

In Austria the field trial focused on the effects of video-based feedback during driver training for young, novice drivers. Twelve young drivers participated in the study; half of them had received video-based feedback during their learning phase, the other half had not (*Figure 3.5*). To see whether the training method affected the driver behaviour immediately after licensing and in the first phase of solo-driving, the behaviour of the twelve participants was monitored for one to three months. Data were collected by means of a data acquisition system (pdrive system®) that registered video images and GPS position as well as acceleration and deceleration forces. The video registration was event-triggered, i.e. only images of a short period before and after a predefined event, such as sudden harsh braking, were actually registered. An SQL (Structured Query Language) database was designed and programmed for subsequent data storage and efficient filtering of relevant data segments for further analyses.



Figure 3.5 left: sample video shot of an error marking, right: driving teacher providing feedback

Three types of driving events, categorised in severity levels, were classified, based on thresholds of either longitudinal or lateral acceleration values and a combination of both. Based on this, risk scales were developed as a measure of safety relevant events per hour driven. Preliminary statistical analyses indicated that the drivers who had had video-based feedback during the training had fewer risk events than those who had not.

Overall, this trial showed that the applied in-vehicle data acquisition system is suitable for recording ND behaviour, and for identifying and developing risk indicators and risk scales based on driving parameters.

3.3 Cyclists: combining- in-vehicle and site-based ND data

The Dutch field trial explicitly focused on the vulnerable group of cyclists and their interaction with motorized vehicles. Whereas part of the information about this type of interactions – as well as about the interactions between pedestrians and cars – can be based on in-vehicle data, it can be assumed that some relevant information will be missing that way and that, as such, a combined site-based and in-vehicle data collection approach would enrich the information. Furthermore, the combination would give an opportunity to validate measures from the individual observation methods against each other.

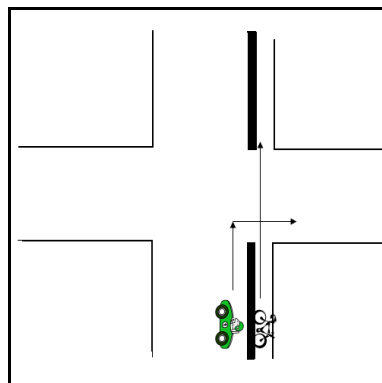


Figure 3.6 Illustration of the potential conflict between a car and a cyclist

The trial was performed in the Netherlands at an intersection where there is a potential conflict between car drivers turning right and cyclists going straight-on. The intersection had a separate cycle path and a traffic light where right turning cars and straight-on going cyclists faced the green light at the same time (*Figure 3.6*).

For the trial, one intersection in an urban area was equipped with two cameras for two weeks. The two cameras were positioned with a different angle so that they provided a broad picture of the area of interest. The cameras only switched on when some movement was detected. For the site-based study, two ways of analysing the data were examined and compared: manual (image-based) analysis, and automatic (video based) analysis.

Additionally, eight cars of people regularly commuting through this particular intersection were equipped with the pdrive system® (see *Section 3.3*) for eight weeks. For this trial, the video equipment was programmed in such a way that it switched on when the driver approached the intersection, as identified by the GPS data. The equipped cars could be identified on the images of the fixed camera by the large dot that was stuck on the roof of the participating cars. In such a way the video images could be matched (*Figure 3.7*).



Figure 3.7 Video image from one of the site-based cameras (left) and from the equipped car (right)

Detailed data analysis of the site-based data set focused on a randomly selected one day period from 06:00 am until 08:00 pm. Speed data were analyzed both manually and automatically. One of the findings was that the manual method was slightly more accurate, but substantially more time-consuming. Furthermore, site-based information about post-encroachment time (PET) and time-to-collision (TTC)¹⁰ indicated that there were fewer conflicts between right-turning cars and straight-on going cyclists if the cars started from a halted position (red light) than from a non-halted position (green light).

In the two weeks of combined site-based and in-vehicle data collection, five relevant encounters between an equipped car and a bicycle were registered. The information from the site-based, high-mounted cameras showed that the non-halted (arriving when the light is green) encounters are relatively more critical than the halted encounters (accelerating after the red light turns green). The in-vehicle measurements showed that drivers look more frequently and for longer in the direction of a potential cyclist in a halted situation as compared with a non-halted situation. Moreover, fixed camera data enables us to define the exact position of both the car and the bicycle enabling, for example, quantifying the time-to-collision. The in-vehicle data, on the other hand, provides more explanatory data.

¹⁰ PET – post encroachment time - is the time between one road user leaving the path of another road user and the other road user reaching that path. TTC –time-to-collision - is the time until a collision between two road users, assuming that both road user would maintain their course and speed.

In conclusion, the Dutch trial showed that combining ND data and site-based fixed camera data yields useful complementary information and, hence, has added value when studying the interaction between cars and vulnerable road users.

3.4 Lessons from instrumented cars for ND research

In principle, in an ND study drivers are observed in their own car. Since they will probably forget about the onboard equipment, this is expected to provide the most reliable information about their everyday driving behaviour. This way, an ND study distinguishes itself from a study with an instrumented car where larger and more visible equipment may remind the driver that he/she is a subject in a scientific study (see also *Section 1.5*). On the other hand, an instrumented car has the advantage of many more sensors and functions for data registration and storage than, at this moment, can practically be applied in someone's private car. In the Spanish trial it was assessed whether a highly instrumented car, i.e. the ARGOS car (*Figure 3.8*), provides relevant information that will be missed with the less advanced ND equipment when identifying incidents.

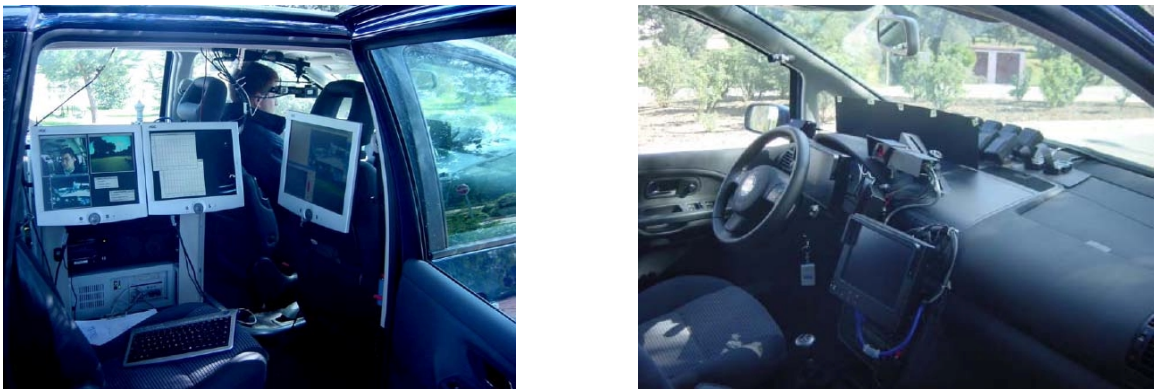


Figure 3.8 The inside of the Spanish instrumented ARGOS car

The ARGOS car can record, among more:

- Car dynamics (e.g. distance travelled, lateral and frontal position, speed);
- Driver-vehicle interaction (e.g. steering wheel rotation, speed, brake pressure),
- Status of various car Indicators (e.g. ABS activation, oil temperature, water temperature, fuel level);
- Environmental conditions (e.g. external and internal temperature, interior noise);
- Driver parameters (eye-movements);
- Video images (seven cameras covering inside and outside of car; *Figure 3.9*).

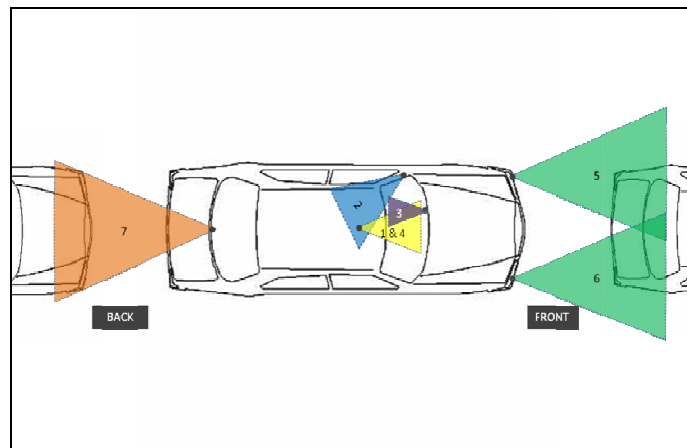


Figure 3.9 Position of the seven ARGOS' video cameras: 1 - 4 are internal, 5-7 external cameras

The study looked at the effect of using a navigation system and mobile phone use on driving behaviour and incidents in a semi-naturalistic way, i.e. without an observer or experimenter in the car. Five experienced drivers participated in the trial and each of them drove the car for four consecutive days. The subjects had to find several unknown addresses, both in an urban and a rural environment. Subjects were allowed to use the onboard navigation system to find the addresses on the second and fourth day of driving; data from the first and third day were used as the baseline for comparison purposes. Data were collected continuously during every trip.

A total of 16 incidents were registered, 11 of which occurred in situations where the driver did not use the navigation system or mobile phone. The sample was too small to try to define meaningful risk levels for the use of these devices. However, the data show that the drivers hardly used them while driving and, if they used them, they generally stopped the car. It cannot be excluded that this is (partly) due to the non-naturalistic nature of the trial.

An important finding was that the identification of incidents by means of just acceleration/deceleration and steering wheel parameters was not reliable enough. Additional analyses of video registrations appeared to be a better source of information for this. Subsequently, once an incident is identified, it is important to go back to the driving and vehicle parameters again, since a seemingly unimportant braking action can, for example, be of critical importance if it is effectuated just at the right moment.

In relation to this, it must be realized that interesting incidents are also those where drivers do not react at all because they are distracted. Per definition, this type of incidents cannot be identified on the basis of just vehicle parameters.

Overall it can be concluded that a combination of vehicle parameters and video data substantially increases the chance of identifying actual safety-relevant events and reduces the number of false positives and false negatives.

3.5 Behavioural effects of Advanced Driver Assistance Systems

The last small-scale trial was conducted in Greece. This study focused on Advanced Driver Assistance Systems (ADAS) and, more particularly, on Forward Collision Warning (FCW) and Lane Departure Warning (LDW) systems. Again, like in the Spanish

trial, an instrumented car was used in a semi-naturalistic way: each of the five drivers drove this car for three consecutive weeks without an observer/experimenter being present. The first week was a baseline period; in the second week the FCW was activated; in the third week the LDW was activated. Each day of the three week period, the subjects had to drive a pre-defined, familiar route of around 40 minutes, including peri-urban, rural and highway sections.

One of the research questions was whether people compensate for the increased safety associated with ADAS by driving in a more risky manner. Another research question was whether distraction by interior or external sources affected driving behaviour. The reason for using an instrumented vehicle was a practical one: implementation of FCW and LDW in people's private car was too costly. However, the trial gave yet another opportunity to test the usefulness and feasibility to extract particular meaningful results out of the various vehicle parameters and video data.

The main vehicle parameters recorded were lane deviation, indicator activation, steering angle, brake activation, headway, and acceleration. In addition, video cameras recorded the driver, as well as the forward and backward road view. The system also recorded GPS.

This trial showed that drivers were hardly involved in behaviour or actions that were not primarily related to operating the car. Again this may be the result of driving an instrumented car rather than their own car. When FCW and LDW were activated these types of secondary behaviours were somewhat higher. However, since these conditions always followed the baseline period, the difference could also be the result of more experience with the task. It was also found that when the driver looked at the scenery when driving, this coincided with larger speed variation and larger steering movements. Comparison of the recorded data and the self-reported data showed that in case of a safety-related event, participants attributed these to other road users rather than to themselves.

In conclusion, the Greek trial showed that self-reported trip data and questionnaire data are useful additional instruments to reveal biases in the sample and to uncover particular biases towards participants' own interpretation of their behaviour and the traffic situation.

3.6 In summary

In summary, it can be said that the PROLOGUE field trials confirmed the potential value of the ND approach for obtaining knowledge about various aspects of road user behaviour and road safety. This was true for all different types of technology, though, not surprisingly, more complex technology resulted in more detailed information, but at the same time required more effort for data reduction and analysis. More specifically, the trials contributed to the state-of-the-art of ND research by

- Creating and implementing a methodology to integrate site-based continuous data collection with in-vehicle data recording.
- The development of a tool for analysing geo-spatial information in the context of driving.
- Adjusting, integrating, and comparing various in-vehicle technologies, in conjunction with complementary data.
- Creating a wide range of ND experiences for discussing the trade-off between the complexity of the data collected and the research questions that can be addressed.

3.7 Further reading

Israeli trials

Lotan, T., Albert, G., Ben-Bassat, T., Ganor, D., Grimberg, E., Musicant, O., Hakkert, S. and Toledo T. (2010). *Potential benefits of in-vehicle systems for understanding driver behaviour; a series of small-scale ND studies in Israel*. PROLOGUE Deliverable D3.2. Or Yarak, Hod Hasharon, Israel

Austrian trial

Gatscha, M., Brandstätter, C. & Pripfl, J. (2010). *Video-based feedback for learner and novice drivers; a small-scale ND field trial in Austria*. PROLOGUE Deliverable D3.3. Test & Training International, Teesdorf bei Baden, Austria

Dutch trial

Christoph, M., Nes, N. (SWOV), Pauwelussen, J., Mansvelders, R., van der Horst, A.R.A. and Hoedemaeker, M. (TNO) (2010). *In-vehicle and site-based observations of cyclists; a small-scale ND field trial in the Netherlands*. PROLOGUE Deliverable D 3.4. TNO, Soester-berg, The Netherlands.

Spanish trial

Valero-Mora, Pedro M., Tontsch, A., Pareja-Montoro, I., Sánchez-García, M. (2010). *Using a highly instrumented car for naturalistic driving research: a small-scale study in Spain*. PROLOGUE Deliverable D3.5. INTRAS/University of Valencia, Valencia, Spain.

Greek trial

Touliou, K., Margaritis, D. (2010). *Effects of Forward Collision and Lane Deviation Warnings on road user behaviour; a small-scale Naturalistic Driving study in Greece*. PROLOGUE Deliverable D3.6. CERTH/HIT, Thessaloniki, Greece.

Summary and integration

Backer-Grøndahl, A., Lotan, T., Van Schagen, I. (2011). *Summary and integration of a series of Naturalistic Driving field trials*. PROLOGUE Deliverable D3.7. TØI Institute of Transport Economics, Oslo, Norway.

4 Application areas and potential users

As shown in the previous two Chapters, ND research results in huge amounts of data that can help to answer a wide variety of research questions. As indicated these research questions not only relate to road safety, but also to environmental aspects of driving as well as to traffic planning and management. Given the time and costs involved in ND research it is important to ensure that the resources are used in an efficient way. There must be sufficient 'customers' and the results must match their interests and help to fill their knowledge gaps. For this reason, PROLOGUE made an inventory of potentially relevant research topics, user interests and potential beneficiaries. Several tools were applied to collect this information, including literature analysis, questionnaires, discussions with members of the PROLOGUE User Forum, and a number of international and regional workshops.

4.1 Research topics

As part of the US SHRP2 study (see *Section 2.2*) a comprehensive list of research questions for an ND research study were developed, consisting of a total of more than 400 questions. With this list as a source of referencing, PROLOGUE took a somewhat different approach to identify the potential research questions, namely by defining the research topics in terms of combinations of

- 1) Eight categories of driving behaviour and driver states:
 - a. Distraction and inattention
 - b. Fatigue, sleepiness and other impairments
 - c. Decision-making, driving errors, driving style, and general driving performance
 - d. Lane change and lane position
 - e. Speed and acceleration
 - f. Gap acceptance
 - g. Aggressive driving
 - h. Learning
- 2) Four conditions (plus two general/combined ones) under which driving behaviour may be observed:
 - a. Driver background factors and trip characteristics
 - b. Road system, road environment, and ambient conditions
 - c. Vehicle design, equipment, and condition.
 - d. Traffic volume and composition – interaction with other road users

This resulted in a two dimensional matrix of 54 cells as illustrated in *Figure 4.1*. The complete matrix can be found in *Appendix II*. This matrix can be used as a frame for structuring research topics in a general way, and, from there, for specifying and prioritizing the research questions. These specific research questions are supposed to comprise observing driver behaviour not only in relation to road safety, but also in relation to traffic management and environmentally friendly driving or eco-driving. The matrix only deals with ND research in its purest form. It does not contain research questions

related to ND research in more applied, experimental settings, like driver training, training for green driving, or for providing feedback and incentives to drivers for both safe and economical driving.

SITUATION BEHAVIOUR	Driver background, trip characteristics	Road system/ environment, ambient conditions	etc.
Distraction and inattention	- How often are young drivers engaged in distractive activities? - How often are drivers of lease cars distracted? ----- etc.	- Is the prevalence of external distraction related to road environment? - Does the presence of passengers lead to distraction? ----- etc.	-----
Fatigue, sleepiness, other impairment	- How often and under what circumstances do drivers drive while fatigued? ----- etc.	- Is falling asleep while driving more likely on monotonous roads? ----- etc.	-----
Decision making, driving errors/ style/performance	- What is the role of inattention in intersection errors or conflicts? ----- etc.	- Are drivers less likely to pass with centre line rumble strips? ----- etc.	-----
etc.	-----	-----	-----

Figure 4.1 Excerpt of the PROLOGUE ND research topic matrix

4.2 User interests

As a starting point, PROLOGUE considered ND research potentially interesting for a wide variety of transport-related professionals, including not only road transport researchers, but also car industry, insurance companies, driver training and certification organisations, police, road authorities, and policymakers. To get a better feeling of the exact interests of these stakeholders, two international and six national/regional workshops were organized. In addition, two small-scale surveys were performed; one among members of the PROLOGUE User Forum and another among workshop participants. *Table 4.1* provides some factual and quantitative information about these activities.

4.2.1 Road safety

On the whole, the workshops and the surveys demonstrated that there is much interest in ND research and its potential to contribute to new, important knowledge. Though most participants were at least vaguely familiar with the concept of ND, it turned out that some further clarification was needed to ensure a mutual basis for further discussions. In general, stakeholders precisely spotted the typical black areas of transportation research, where traditional methods do not provide the information needed to make traffic more efficient, safer and greener.

The main interest of the potential users of ND knowledge appeared to be in road safety topics, and more precisely, in risk-taking behaviour, pre-crash behaviour, crash avoidance behaviour, and driver conditions. Whereas so far ND research almost exclusively focus on passenger cars and trucks, it was stressed repeatedly that ND research would also need to focus on the safety of pedestrians and cyclists either by developing a way to 'equip' these road users with cameras or by site-based observations. In many countries the safety developments of these vulnerable road users stay behind those of car drivers. Similarly, powered two-wheelers are considered an important group of road users when looking at safety. More than for any other category, issues of behaviour and crash causation are still not well understood and Naturalistic Riding is therefore considered a major source of information to tackle the particular risk of users of powered two-wheelers.

Table 4.1 Some factual and quantitative information about various PROLOGUE activities

	Where	When	Participants/ respondents/
Regional workshops	Norway/Sweden	October 2010	} 194
	Austria/Germany	November 2010	
	Netherlands/Belgium	November 2010	
	Spain/Portugal	December 2010	
	Great Britain/Ireland	January 2011	
	Greece	February 2011	
International workshops	Brussels	February 2010	54
	Vienna	June 2011	61
User Forum	---	As per 15 July 2011	364
Survey 1	Among User Forum via internet	December 2009	72
Survey 2	Among workshop participants via internet or on paper	October 2010 - February 2011	107

4.2.2 Environment and traffic management

The bias towards road safety interests is at least partly explainable by the fact that road safety professionals were overrepresented in both the workshops and the survey and that in turn mainly resulted from the focus of the partners in the PROLOGUE consortium. Subsequent targeted actions towards environmental organizations showed that also in this area ND was considered a promising method for several research questions. Relevant variables can easily be included, even if a large-scale ND study were to primarily be focused on road safety. Having so much data from everyday driving would be very useful to better understand the relationship between, on the one hand, the general characteristics of different vehicle types in different driving conditions, operated by people with different driving styles, and, on the other hand, the exhaust emissions and fuel consumption.

ND data could also provide relevant information for traffic management purposes. For example, route and lane preferences, preferably in relation to various background variables, can be relevant in this respect. Another example is that ND data can provide empirical input about road user behaviour to validate and develop both macro and micro simulation models.



Figure 4.2 ND data as input for dynamic route information
(Source: www.ops.fhwa.dot.gov)

4.3 Beneficiaries

Stakeholders' expectations of ND research are high and diverse. To cover the various interests it will be essential to include as many variables as technically and organizationally possible (see *Chapters 5 and 6*) as long as this effort does not imply unreasonable additional costs. However, some management of these high expectations may be needed to avoid disappointments. One important issue to clarify is the relatively long time between data collection and the availability of the results. In this respect, dissemination of some preliminary results may be considered.

ND research is expected to benefit many, and in the end it will be the 'universal road user', who benefits. In a way, it will also be the 'universal tax-payer' who benefits, considering that ND research supports reduction of crashes and injuries, reduction of environmental impact, and reduction of congestion. Hence, ND research supports reduction of the macro-economic costs of the transport system.

ND results may take diverse paths towards the road user. Looking at the respondents of the PROLOGUE surveys and the participants of the workshops, vehicle manufacturers and suppliers will benefit from additional knowledge about their clients to improve vehicle design. In particular, advanced driver assistance systems and other ITS solutions can be improved by using ND data for evaluation. The insurance industry will benefit from safety improvements and enhanced predictability of risk. Road administrations may benefit by using ND results for avoiding any unnecessary expenditure and allocating budget for the most efficient measures in terms of capacity and safety. Mankind will benefit globally if ND knowledge is used to make vehicles more fuel-efficient. Researchers, finally, will get an innovative tool to support all other stakeholders in making transport more efficient, greener and safer.

4.4 Further reading

Van Schagen, I., De Craen, S., Van Nes, N., Eenink, R. (2010). *The areas of interest of potential users for naturalistic observations studies*. PROLOGUE Deliverable D1.2. SWOV Institute for Road Safety Research, Leidschendam, The Netherlands.

Sagberg, F., Backer-Grøndahl, A. (2010). *A catalogue of applications and research topics for future naturalistic driving studies*. PROLOGUE Deliverable D1.3. TØI Institute of Transport Economics, Oslo, Norway.

Eichhorn, A., Winkelbauer, M. (2010) *1st PROLOGUE Workshop Minutes*. Deliverable D5.6. Kuratorium für Verkehrssicherheit KfV, Vienna, Austria.

Eichhorn, A., Van Schagen, I. (eds.) (2011) *Minutes of six regional workshops about Naturalistic Driving*. PROLOGUE Deliverable D5.11. Kuratorium für Verkehrssicherheit KfV, Vienna, Austria.

Eichhorn, A. (2011). *Final PROLOGUE Workshop Minutes*. PROLOGUE Deliverable D5.13. KfV Kuratorium für Verkehrssicherheit, Vienna, Austria.

5 Technical requirements

Collection of data through the ND approach requires consideration of many different technical aspects in order to ensure successful outputs. These technical requirements are significant and complex, and relate to data acquisition, data capture, storage, management and analysis. Within PROLOGUE an inventory of the experiences so far was made, including in the project's own field trials (*Chapter 3*).

5.1 Data acquisition equipment

5.1.1 Data logging

Typically, in an ND study 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. This data logging system is an essential part of the ND approach. Careful consideration and utilisation of appropriate data logging equipment can be the difference between a successful and unsuccessful study. Most modern-day data acquisition systems are telemetry-based systems powered by an uninterrupted, 'mains' type supply. They are connected to a more powerful computer (wired or wirelessly) for instant data download at rates of up to 1000Hz.

There are a number of different types of approaches to choosing data acquisition systems; these can be classified as follows:

- Purchase of ready-made, 'off-the-shelf' systems
- In-house design
- Hybrid systems

The advantages and disadvantages of these are as described in *Table 5.1*.

Table 5.1 Advantages and disadvantages of three types of data acquisition systems

Data acquisition system	Advantages	Disadvantages
'Off-the-shelf'	Ease of use Ease of instalment Relatively cheap	Difficulties adding extra channels Difficulties responding to new data-logging requirement
In-house design	Can be tuned to specific research needs Can use individual 'top-of-the-range components (e.g. GPS receiver)	Knowledge and expertise required to develop the system Knowledge and expertise required to make the system work
Hybrid system	Allows flexibility of component specification System expansion relatively simplistic Relatively cost-effective	Requires some software and programming expertise

5.1.2 Specialist sensors

In an ND study, a simple data-logging capability may not be enough by itself, depending on the study objectives. Therefore the data logging can be enhanced with specialist sensing equipment. Such sensors can be mounted to the vehicles themselves and linked to the data acquisition system to record information on channels such as pedal position, steering wheel position, road speed, and suspension movement.

Specialist sensors cover a large and diverse equipment group and are often tailored to a particular application, vehicle or installation requirement. In almost all cases, if there is a requirement for a specific measurement, then there will be a sensor available to do this.

It is worth bearing in mind that specialist sensors can carry problems which can be manifold and complex to resolve. It will inevitably become a trade-off between the requirement for a dedicated sensor and the added problems they bring. Common issues with these specialist sensors involve their added cost (sensors can easily cost upwards of 1000 each), the requirement therefore for protecting these sensors and the subsequent replacement complexity should they become damaged. Furthermore, calibration of high sensitivity sensors can be problematic and their integration into a data acquisition system will almost inevitably be complex.

5.1.3 Video data

Video data is essential in understanding or interpreting the data recorded by the sensors and in understanding driver behaviour in general. Significant developments continue with regard to cameras, frame rate, resolution, zoom level and storage capacity.

Video data analysis will almost certainly be necessary for an ND study that aims to evaluate distraction or inattention in drivers and to study driver behaviour in general. Studying visual behaviour in particular is currently complex and expensive as it requires high sensitivity eye-tracking equipment and/or machine-vision techniques. An alternative could be the use of event-triggers to highlight areas of interest in the data, such as high longitudinal 'g', lateral accelerations or yaw. This can be complemented by manual video analysis to determine the exact nature of the distraction or inattention at specific points of interest. This technique relies on good quality video data in terms of, but not exclusive to, the number of camera and their angles, video resolution and frame rate.

For a more complete understanding of both vehicle and environment factors it is recommended to use a minimum of four cameras, the positions of which will ultimately be dictated by the nature of the data requirements. The red dots (and associated shaded areas indicating the fields of view) in *Figure 5.1* show a basic layout for capturing good quality video data about the driver, the vehicle and the environment. It is clear, however, that if an alternative shot is required, another camera will have to be introduced or a compromise will have to be made with the existing arrangement.

Camera positioning will also be dictated somewhat by other factors, some of which can be difficult to resolve (such as suitable mounting positions or available space within the vehicle) and others which need careful consideration (such as ethical constraints restricting images of passengers). In most cases a compromise between meeting the ideal video requirements and finding a practical solution will need to be made.

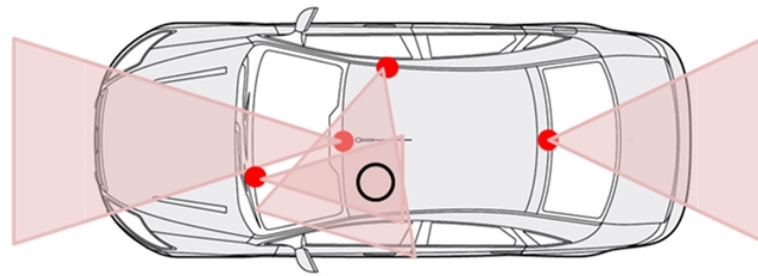


Figure 5.1 Video configuration for a left-hand drive passenger car

Within PROLOGUE, experiences with manual analysis of continuous video recording proved to be time-consuming, in particular if, as preferred, the video data is analyzed by two persons. When triggering thresholds were employed, there appeared to be a large number of ‘false positives’: an event was automatically identified as relevant, but further visual inspection indicated nothing of interest. Similarly, there were also false negatives, i.e. events that were not selected by the automatic threshold approach, but according to visual inspection were indeed relevant incidents. It is therefore concluded that continuous processing of video data is relatively essential although some means of automatic coding and event detection is also required.

5.1.4 Eye tracking

Of significant relevance to the subject of video data is the subject of eye tracking. This field is not solely devoted to the science of eye tracking (it is often simplified to this) as it also includes subject areas such as face recognition, glance analysis and sleep measures amongst others.

On the whole, the use of eye-tracker equipment is relatively specialised and the analyses of the generated data can be somewhat complex and time-consuming. Nevertheless, if the study objectives specifically involve in-depth determination of visual behaviour during the driving task, then such equipment should be considered since robust results can be produced.

An alternative and simple method of analysing visual behaviour within the vehicle is to carefully monitor and code high quality video footage of the driver’s face. Analysis of the footage by trained analysts allows coding of a wide range of behaviours. This can include gesture, mood, glance, sleepiness metrics and additional tasks such as eating or mobile phone use. This technique relies on the availability of ‘man hours’ and good training. However, the footage will need to be viewed by trained analysts in order to extract the best quality data. Analysis of video data is somewhat limited for in-depth determination of visual behaviour.

Therefore, given the costs and workload associated with this type of data capture, one should only consider using eye-tracking equipment if there is (also) a specific focus on visual behaviour.

5.2 Data storage and management

An ND study generates significant quantities of data and therefore data storage and management is a major consideration. Data storage devices should be inconspicuous but easily accessible for data retrieval. In previous ND studies, data has been retrieved via removable technology such as USB hard drives and flash cards, via direct download from the vehicle, or via wireless technology.



Figure 5.2 Data storage and management is a major consideration in an ND study (Source: www.keyzone.com)

Rigorous data uploading and back-up procedures are essential to minimise data loss. This also includes data verification and validation. A database should preferably be relational and support SQL programming. This enables rapid access to the data stored and provides features for more advanced scripts such as evaluating trigger levels of vehicle dynamics. Video data can be stored on a file server or within a database with each frame being stored as a separate image (JPEG or BLOB), or the complete video can be stored as a binary file. Careful consideration should be given to the storage capacity of the database in advance to ensure that all relevant data can be stored throughout the course of the study. For example, the large-scale SHRP2 ND study in the U.S. is expected to result in 1 petabyte of data, i.e. one million gigabytes. A number of functions need to be provided by the software chosen in order to support data analysis. These include

- Database query functionality (e.g. SQL);
- Signal processing of numerical data;
- Fully customizable mathematical computation, analysis, and algorithm development functionality, automatic or semi-automatic calculation of performance indicators, and application of trigger algorithms to find events of interest (e.g. lane changes, near crashes, jerks);
- Image processing of video data (e.g. machine vision algorithms to detect traffic signal status);
- Grouped analysis of data (e.g. scripts);
- Export results function to tabular format or statistical packages.

Many previous studies have developed custom software to meet analytical needs. Perhaps most importantly is the need for data reduction in order to derive data to be analysed. This is necessary since the “core” data set may comprise many hours of video footage. Data reduction leads to the extraction (through data mining) of both the specific events of interest and the end product (i.e. the data to be analysed) that indicate an event in the driving process has occurred. In general the greater the video capability the more information that will be gathered and the more analysis that can be conducted. However, the issue of ‘false positives’ is still prevalent.

5.3 Data analysis

A number of software tools can be utilised to form an analysis package. SQL software is probably the most commonly used tool for database queries whilst for computation, mathematical software such as MatLab is probably the most appropriate tool. For statistical analysis, widely used applications are appropriate (e.g. SAS, SPSS). Where necessary, it may be that custom solutions (proprietary) with user friendly graphical interfaces are required, particularly for the analysis of large and complex datasets.

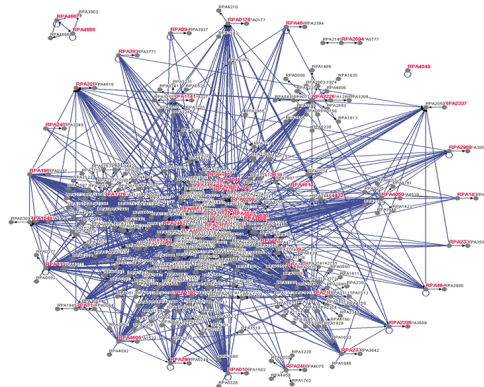


Figure 5.3 Analysis of relational data (Source: www.mippi.ornl.gov)

5.4 In summary

- Some means of logging data from each vehicle is essential for a large-scale ND study.
- Off-the-shelf systems are probably the simplest and most economical devices. In-house design devices and hybrid systems will also be suitable, but these are more expensive and they may not always be entirely fit-for-purpose.
- Supplementary data logging capabilities may be required for specialist sensing (depending on the overall study objectives).
- Careful consideration of data management is warranted throughout. Vast amounts of data can be produced in an ND study and data quality, back-up, upload, storage and download are all critical elements. An essential consideration of a large-scale study is whether the data should be stored centrally or locally.
- Appropriate tools for data analysis are required. These include SQL (for specific database queries), MatLab (for mathematical processing) and SPSS/SAS for statistical analysis.

- Video-data is essential if driver visual behaviour (and indeed, general driver behaviour) is to be studied. Eye-tracking equipment is also a very useful tool for measuring visual behaviour but should only be used if the main objective of the study involves examining this specific behaviour.
- A minimum of four camera positions should be used to understand driver behaviour and road context.
- However, some means of automatic video processing is essential and some means of filtering out false positives is also required. This can be undertaken in conjunction with the application of specific 'signatures' within the data that indicate that an event of significance has occurred.

5.5 Further reading

Koskinen, S., Kovacs, A., Dreher, S., Welsh, R. (2010) *Tools for Database Handling*. TeleFOT Deliverable D4.1.1. TeleFOT website <http://www.telefot.eu/pages/index/?id=6>

Welsh, R., Reed, S., Talbot, R., Morris, A. (2010). *Data collection, analysis methods and equipment for naturalistic studies and requirements for the different application areas*. PROLOGUE Deliverable D2.1. Loughborough University, Loughborough, UK.

6 Methodological considerations

When conducting an ND study, there are various methodological considerations to make in order to ensure that it is a scientifically sound study resulting in reliable and valid conclusions. Important topics to consider are selection of subjects, definition of variables, study design, and data analysis.

6.1 The 'Festa V' approach

As a general approach, the FESTA handbook¹¹ on the implementation of Field Operational Tests distinguishes the various steps that typically have to be considered when conducting such a study. This approach has got known as the 'Festa V' (Figure 6.1). This approach is to a large extent also applicable to an ND study, and the planned update of the FESTA handbook will make this explicit.

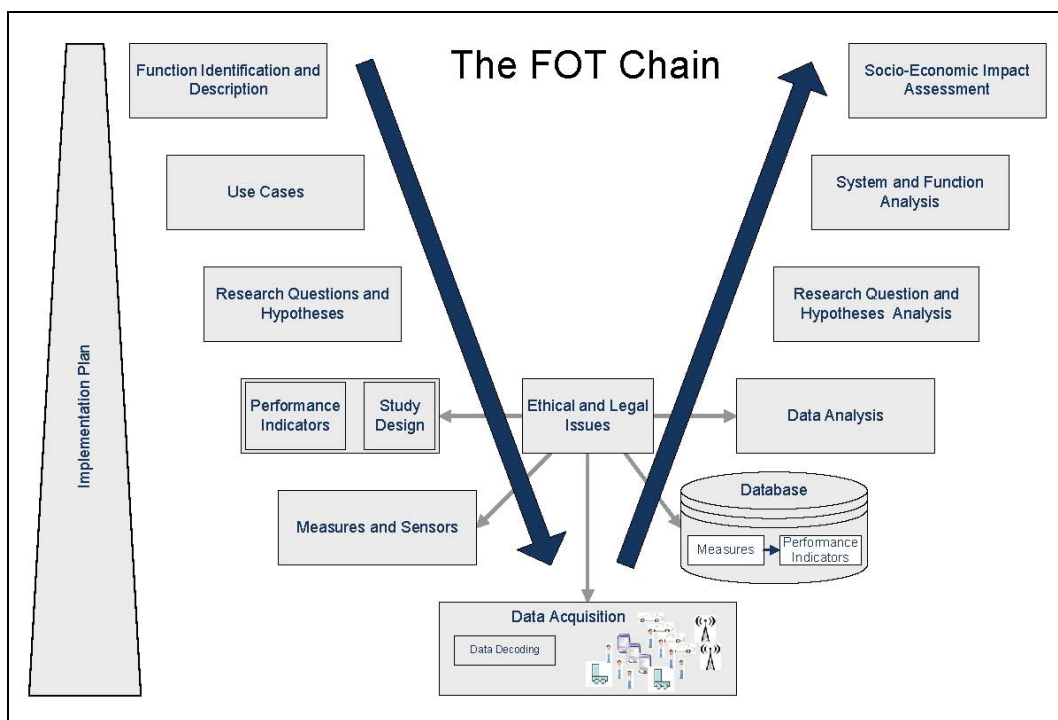


Figure 6.1 Festa V: the stepwise approach of a Field Operational Test with the arrows indicating the time line (Source: Festa Handbook 2008)

6.2 Selection of vehicles and participants

One of the first issues to consider after the research questions have been defined is the selection of vehicles and drivers to participate in the study. Clearly if one is interested in buses and bus drivers then a different sample is needed than if one is interested in young passenger car drivers. A very general research question could be how driver characteristics and vehicle type relate to driving behaviour and crashes or near crashes. This means that the sample of drivers and vehicles need to be diverse and contain the variation of interest. With respect to the selection of drivers it is important to

¹¹ FESTA Consortium (2008) FESTA handbook. D6.4 of the Field opErational teSt supportT Action (FESTA).

be aware of a self-selection bias. Since participation will always be on a voluntary basis, the participants may be very different road users than those who do not want to participate. Pre-screening participants according to a personality trait/attitude using psychometric instruments will allow the researcher to ensure that a range of drivers with the desired characteristics are included within the study, and, together with biographic information, will give an indication of the self-selection bias. With regard to the selection of vehicles it is important to realize that newer cars have more or different information available through the CANbus or OBD than older cars. In relation to that, it is also important to realize that there may be a relationship between type/brand of vehicle and its driver on relevant variables such as driving style.

Another topic here is the sample size. How many participants are needed in an ND study? In general, the larger sample the greater the chance of finding an effect. However, it does not make sense to strive always at the largest possible sample. With (very) large samples, already very small differences between groups may appear to be statistically significant, although the meaning of this difference may often be irrelevant. The appropriate sample size for an ND study depends among other things on the design and setup of the study and the hypotheses that are going to be tested.

Regarding the length of data collection, it must be concluded that at least a couple of months are required. In particular if the study is interested in events that are not likely to happen very frequently, e.g. (near) crashes, a sufficiently long period of data collection is necessary. As an indication, in the 100-car study in the U.S. data were collected for 12-13 months; the recently started follow-up SHRP2 study aims at a data collection period of one to two years. Depending on the kind and number of questions to be answered in the study as well as the number of participants and vehicles, a minimum duration of 12 to 18 months is recommended.

6.3 Variables to be measured

ND research is generally interested in many different aspects of the traffic task and, therefore, needs to measure many different variables. Which variables these exactly are depends again on the research questions. The variables can be grouped by

- Demographic and personality variables (e.g. age, gender);
- Driving behaviour variables (e.g. number of lane changes);
- Driver distraction and state variables (e.g. mental workload, fatigue);
- Vehicle condition variables (e.g. vehicle type, presence of ACC);
- Vehicle variables (e.g. speed, steering wheel angle);
- Weather and light conditions variables (e.g. precipitation, temperature);
- Traffic condition variables (e.g. traffic density, traffic composition);
- Road variables (e.g. speed limit, lane width)

Appendix III contains a comprehensive list of variables that may be relevant to be measured during an ND study.

In general it is useful to gather as many variables as practically possible. Even if no specific impacts are expected of certain variables, some outcomes may be explained better with more knowledge about the drivers, the roads or the vehicles.

Driver distraction is described in a separate list of variables. The reason is that the 100-car ND study in the U.S. (see *Chapter 2*) found that distraction was a potentially contributing factor in more than 80 percent of all safety-critical events. Therefore, the prevalence and risk of (various forms of) distraction is an important road safety topic and it is a topic that is difficult to measure with research methods other than ND. Relevant variables are mental workload, fatigue/drowsiness, distraction from the primary task (e.g. eye tracking), presence and use of in-car devices and the performance of tasks other than the driving task.

With respect to road variables, as a minimum, the three main road categories have to be differentiated: urban, rural, and motorway. Subcategories can be distinguished if relevant for the research question at stake. Subsequently, roads can be classified according to, for example, their design and layout (number of lanes, horizontal and longitudinal profile, etc.) and legal aspects (speed limits, right of way, etc.). In principle, this type of data can be scored on the basis of the ND video recordings from the vehicle. However, to facilitate the task and to save analysis time, it is to be preferred to have this type of information available in an electronic map linked to the geographical position of the vehicle. This electronic map would need to contain information about, at least, the type of roads and the speed limits in force. Other relevant information could be various road design characteristics and the location of speed cameras.

Some traffic condition variables could be estimated indirectly by using day and time of the day, if possible supplemented by data from relevant road authorities. However, more detailed information about traffic conditions and about the presence of other road users has to be collected from the in-vehicle video recordings of both the situation in front and behind the vehicle. Since analysis of video data is very time-consuming, one has to be selective when choosing which sections of data to analyse. This type of analysis should be driven by the hypotheses that are being tested.

6.4 Design of an ND study

Typically, an ND study is observational rather than experimental in nature. This makes it more difficult to determine causal relationships between dependent variables (e.g. road design, vehicle characteristics) and independent target variables (e.g. road user behaviour or crash involvement). Contrary to a true experimental study where all important variables are systematically controlled and varied, this is not possible in an ND study where participants just drive their everyday trips. This way, an ND study resembles an epidemiological study that is common in medicine and that aims to identify the factors that increase the likelihood of getting a particular disease or other health-related condition.

Generally, in epidemiological studies the number of events (diseases or crashes) in one group of individuals is compared to the number of events in another group, and these groups vary on one or several potentially relevant characteristics (e.g. age, fatigue). If the number of events in both groups differs, it can be inferred that that particular factor may be important. Obviously, one must be aware that the identified factor (e.g. insufficient sleep during the previous night) may be caused by another relevant factor (e.g. residual alcohol because of a late night party that night before).

A very relevant study design for ND research is the case-crossover study, or within subjects design, where in fact the subject is his own control (*Figure 6.2*). For example, the number of sudden brakes during a telephone conversation is compared to the number of sudden brakes of that same person when he is not having a telephone conversation, but in situations that are otherwise as comparable as possible (traffic condition, road condition, time of day, etc.). The most important advantage of case-crossover studies is that personal and personality differences cannot explain observed

differences. Therefore, a case-crossover design is recommended for an ND study that aims to identify the relative risks of particular behaviour.

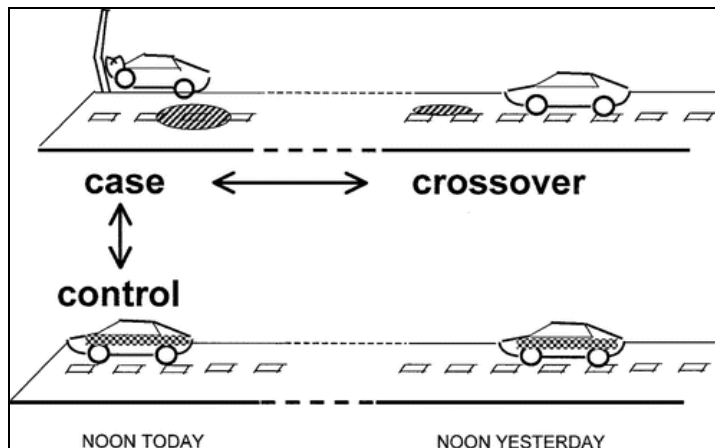


Figure 6.2 A sketch of the case-crossover design.
Source: Maclure & Mittleman, 2000¹²

6.5 Statistical analysis methods

ND studies result in huge amounts of data. Not all of this data will be relevant. What is relevant depends on the specific research questions. A first step then is to identify and label the events of interest, e.g. crashes, near crashes, safety-relevant behaviour. Subsequently, these events, and comparable non-events can be related to potential explanatory variables.

Definition and identification of events is not that easy. One possibility is to define trigger variables that might point to interesting events. For example, a 'very harsh' braking might point to a near collision. However, a subsequent decision is how to define exactly what is meant by 'very harsh'. If we set a low threshold, we may identify too many events that are actually not an event (false positives). If, on the other hand, we set up a high threshold, we may end up with too many missed events (false negatives).

In the 100-car ND study six trigger variables were defined. Initially, they were all set at a rather liberal level which resulted in a large number of possible events. The thresholds were subsequently tightened by trial and error to minimize both the false positives and the false negatives. Another option is to perform automated selection based on a statistical design. The triggers are the experimental factors, and their liberal and restrictive levels are the settings of the factors. An 'experiment' corresponds to the classification of the valid and invalid events defined by the trigger settings. Triggers that are not influential are discarded. Triggers that have a substantial effect on the detection are investigated more closely.

ND data bases generally contain data on a large numbers of variables. Therefore, assessment of the relationship between variables of interest and an event nearly always involves statistical modelling of data. If a model coefficient deviates statistically significant from zero, this is taken as evidence for an effect of the corresponding explanatory variable.

¹² Maclure, M., Mittleman, M.A. (2000) Should we use a case-crossover design? *Annual Review of Public Health*, 21, 193-221. DOI: 10.1146/annurev.publhealth.21.1.193

Since the relationship between real crashes, near crashes, critical events, etc is often assumed, but not yet scientifically established, one has to be careful in combining these event types when looking at their relationship with other variables.

6.6 Organizational issues

For an ND study to proceed smoothly, a plan of action must be developed which documents the scientific, technical, administrative and procedural activities and tasks that are needed to successfully complete it. *Figure 6.3* provides an overview of the 22 critical activities and tasks which are necessary to run a successful ND study. These activities and tasks are documented drawing on lessons learned from Field Operational Tests conducted in Europe, the United States, Japan, Australia and elsewhere, and documented by the FESTA project, but that are equally applicable to ND research.

		Set Up/Design	Preparation	Data Collection	Completion
1	Convene teams and people	█			
2	Define aims, objectives, research questions & hypotheses		█		
3	Develop project management Plan		█		
4	Implement procedures for stakeholders communication		█		
5	Design the study		█		
6	Identify and resolve legal and ethical issues		█	█	
7	Select and obtain Vehicles		█		
8	Select and obtain systems and functions to be evaluated	█	█		
9	Select and obtain data collection and transfer systems		█		
10	Select and obtain support systems		█		
11	Equip vehicles with technologies		█		
12	Implement driver feedback and reporting systems		█	█	
13	Select / implement relational database for storing data		█	█	
14	Test all systems to be used according to specifications		█		
15	Develop recruitment strategy and materials		█		
16	Develop driver training and briefing materials		█		
17	Pilot Test equipment, methods and procedures		█		
18	Run the FOT			█	█
19	Analyse the data			█	█
20	Write minutes and reports	█	█	█	█
21	Disseminate the findings			█	█
22	Decommission the study				█

Figure 6.3 Generic guide to scheduling a Field Operational Test (Source: FESTA Handbook 2008)

6.7 In summary

- The exact research questions determine the desired composition of the participants, the vehicles included and the variables studied. In case of an overall data collection effort, the participants must represent the general driver population and the most popular vehicles must be included.
- Regarding selection of participants it must be kept in mind that participation in an ND study is voluntary. This potential 'self-selection' can have a biasing effect.
- Regarding vehicle selection it is important to realize that newer cars have more or different information available through the CANbus or OBD than older cars.
- Since an ND study is observational rather than experimental in nature, it is difficult to establish causal relationships. Therefore, a case-crossover study design, also known as a within subjects design, in which the participant is its own control is often a suitable design for an ND study.
- It is desirable to develop an automated procedure to identify important events in the data. There are an increasing number of statistical tools for this. It is important to minimize false positives and false negatives.

6.8 Further reading

Groenewoud, C., Schoen, E., Malone, K., Jonkers, E., Hoedemaeker, M., Hogema, J. (2010). *Methodological and organizational issues and requirements for ND studies*. PROLOGUE Deliverable D2.2. TNO, Soesterberg, The Netherlands.

FESTA Consortium (2008) *FESTA handbook. D6.4 of the Field operational test support action FESTA*. Field Operational Test Support Action (FESTA) Project, European Commission.

Montgomery, D.C. (2009). *Design and analysis of experiments* (7th edition). New York: Wiley.

Neale, V.L., Klauer, S.G., Knipling, R.R., Dingus, T.A, Holbrook, G.T., and Petersen, A. (2002) *The 100 Car Naturalistic Driving Study; Phase I – Experimental Design*. Contract No. DTNH22-00-C-07007. Blacksburg, VA: Virginia Tech Transportation Institute.

Antin, J., Lee, S., Hankey, J. & Dingus, T. (2011) *Design of the in-vehicle driving behavior and crash risk study*. In support of the SHRP2 Naturalistic Driving Study. Washington, D.C., Transportation Research Board TRB.

7 Legal and ethical issues

ND research gives rise to a considerable number of legal and ethical issues, related to, for example, obtaining the required permissions, ensuring that the vehicles are safe to operate on public roads, going through the required ethical and human subject review procedures, getting participants' informed consent, complying with data protection and privacy laws, insuring the vehicles, and insuring the project workers for liability.

7.1 General issues

Since the legal and ethical issues are largely dependent on the study design adopted, it is an obligation to obtain legal advice at an early stage of the project.

For an ND study that will be carried out in different countries, it should be noted that the regulations and laws vary from country to country. Even when there are international umbrella regulations such as the EU laws on data protection and privacy, the interpretation of these may vary between countries. As a consequence, an ND study that potentially involves cross-border traffic needs to consider the legal regulations in all relevant countries. Once project partners are known, a review should be made of all applicable laws and regulations in order to identify differences and formulate a project protocol that initially covers all of the varying requirements. In addition, upon recruitment, subjects should be questioned regarding their travel patterns in order to identify any further cross-border considerations not covered by the governing laws of the project partners.

Another important aspect is that all health and safety aspects of the study are fully considered. It must be noted that the lack of a prior risk assessment and therefore insufficient consideration to the safety risks can expose the research organisation to criminal prosecution. Aspects to be considered would include;

- The fitness to drive of the participant, screened for existing medical conditions such as high blood pressure or diabetes;
- The state of the participant's vehicle, for example in the UK this would include ensuring the vehicle held a valid MOT test certificate;
- That the participant held general compliance with safety laws such as seat belt use;
- That participation in the study would not increase burden to the driving task in a way;
- That, for professional drivers, participation in the study would not increase the number of hours required to drive.

7.2 Participant agreement

Initially it should be ensured that any potential participant has the legal entitlement to drive, i.e. holds a valid driving licence, and that they are eligible for insurance. Upon meeting these requirements, participants in an ND study have to sign an 'informed consent' to ensure that they are informed in advance about the purpose of the study, the risks they may incur, the costs that are covered and not covered, the right to withdraw from the study and have the collected data deleted, as well as potential liabilities and the responsible party. One liability to consider is what happens in the event that a participant commits a traffic offence and/or incurs a traffic penalty (speeding ticket,

parking ticket, etc.). Another liability is related to the question of who is responsible for minor damage to the vehicle and payment of any insurance excess. The informed consent would also need to clarify what information is or is not made available to court in case of a crash. This is generally set out in (national) regulations.

The informed consent needs not necessarily be set in the form of a legal contract; it may also take the form of a letter of agreement.

Participants also need to be informed about various practical issues, such as whom to contact in case of breakdown of the in-vehicle ND equipment. The issue of who is allowed to drive, e.g. other household members, and under what circumstances also needs to be considered. It should be possible at all times to identify who is driving the vehicle so that data are filtered and stored only for participants in the study. Taking part in the study should not restrict the everyday normal use of the vehicle by other household members or associated drivers.

7.3 Data protection and privacy

There is no doubt that an ND study will give rise to data protection and privacy issues. On a European level, data protection is regulated by an EU Directive of 1995¹³. However as indicated, national laws may have additional specific requirements. One of the aspects relates to the disclosure of data. If data is published that can result in the identification of a person involved, prior consent of the person in question is required. In particular, video images can give rise to problems. Even though participants will have been informed of in-vehicle video recording, showing the videos to a third party may be a problem if the participant is recognizable.



Figure 7.1 The EU Data Protection Guide (Source: <http://ec.europa.eu>)

Video recording of car passengers needs specific attention. Since it is not known in advance who the passengers will be, these passengers normally will not have given prior consent to being recorded. So, it is questionable whether it is appropriate to have in-vehicle cameras with coverage of the passenger seats. If the presence or absence of passengers is an important variable for some specific research questions, it could be

¹³ Directive 95/46/EC of the European Parliament and of the Council of 24 October 1995 on the protection of individuals with regard to the processing of personal data and on the free movement of such data.

considered to blur the images to make the passengers unrecognizable. In this respect, audio recordings may be even more sensitive, at least if the content of the conversation must remain intelligible. Clear labels indicating that the vehicle is being monitored are required to make passengers aware of the presence of audio or visual equipment. However, it must be kept in mind that these labels will also remind the driver that he/she is being monitored.

Video recording of the external surroundings also needs to be considered. At some places, video recordings of the surroundings may be prohibited, e.g. at border crossings, military locations, or private premises. Video registrations of people on the street, either by the external video in the car or by site-based video registrations, are yet another issue where national regulations have to be respected. By way of a standard it is recommended that any data relating to third parties who have not consented to participating in the study should be anonymized prior to being viewed outside of a designated research group and that this group undertakes a privacy agreement relating to any observations they may have made whilst viewing the data.

Once data have been stored, the data server must be secured. Moreover, any personal ID information should be kept completely separate from the main database and stored with additional protection such as encryption. It has to be recognized that, even when data has been anonymized, it may be possible to deduce who has participated, e.g. from GIS data in the database.

It has to be decided in an early stage of a project what to do with the data once the project has finished. Relevant questions are: Who is then allowed to access and use the data? If data is taken off-line, what aggregated data must be saved? Who will pay for longer term data storage and maintenance? With large amounts of stored data, up to at least several terabytes, the cost to store and manage data is certainly not insignificant.

7.4 Ethical approval

Ethical approval to conduct an ND study may be at least as difficult to obtain as legal approval. Ethical approval is necessarily challenging since it aims to meet all of the personal security and privacy needs of the participants. This may well involve going above and beyond the legal requirements with the need to be handled through the development of a well thought-out protocol specific to the study being undertaken. In many countries and in many organisations there are strict procedures for ethical approval and human subject review. It has to be noted that these procedures can be very time-consuming. Human rights legislation is also relevant, as is the Helsinki Declaration which was adopted by the World Medical Assembly in 1964. Since then, the Declaration has been revised several times and the latest version dates from 2008. The Helsinki declaration among other things describes the right of the individual to be informed and provide prior consent (see *Section 7.2*) and states that the protection and rights of the individual go beyond any interests of scientific progress.

7.5 In summary

In summary, from a legal and ethical point of view, particular attention has to be paid to:

- Obtaining legal advice at an early stage of the project. In the case of a large project, it may be wise to involve a legal expert in the project. It has to be noted that regulations and laws vary from country to country
- Ensuring that participants have legal entitlement to drive the vehicles in question and are eligible for insurance.

- Formalizing the arrangement with the participants to get their written informed consent. It may not be necessary to do this in a legal contract; a letter of agreement can be used.
- Making sure the data is protected and ensuring privacy. The data server must be secured and personal ID information kept separate from the database and stored with additional protection such as encryption.
- Clarifying and respecting participants' right to withdraw from the study and/or erase data at any given time.
- Gaining ethical approval to conduct the ND study.

7.6 Further reading

Groenewoud, C., Schoen, E., Malone, K., Jonkers, E., Hoedemaeker, M., Hogema, J. (2010). *Methodological and organizational issues and requirements for ND studies*. PROLOGUE Deliverable D2.2. TNO, Soesterberg, The Netherlands.

Barnard, Y., Mononen, P., Gasser, T., Gelau, C. (2008) *FOT requirements, legal aspects, planning and development*. FESTA Deliverable D6.3. Field Operational Test Support Action (FESTA) Project, European Commission.

8 Recommendations for a large-scale European ND study

Considering the work in PROLOGUE as well as the large-scale ND studies in the U.S. and the various Field Operational Tests (FOTs), a series of concrete recommendations for a large-scale European ND study have been formulated. Overall, it can be concluded that a large-scale European study will have significant added value in terms of the following characteristics:

- Overall better understanding of how and why crashes happen;
- A large database for analysing crashes and crash-related behaviour;
- Cross-country comparisons;
- Investigation of environmentally friendly driving, in addition to road safety;
- Investigation of vulnerable road users in addition to car drivers.

8.1 The ND "V"

For the overall planning of a large-scale ND study, a slightly modified version of the FOT's FESTA "V" (Section 6.1) may be a useful tool: the ND "V". Figure 8.1 presents our attempt to come to such an ND "V". The left-hand side of this V shows the various phases in preparing an ND study, and the right-hand side shows the phases related to data analysis and dissemination. An important aspect of the "V" is that there are corresponding phases before and after the data acquisition phase. For example, the definition of research questions and hypotheses on the downward slope of the V corresponds to the analyses of research questions and hypotheses on the upward slope. In the ongoing project FOT-NET2 the FESTA methodology is being revised and adapted to ND studies in addition to FOTs.

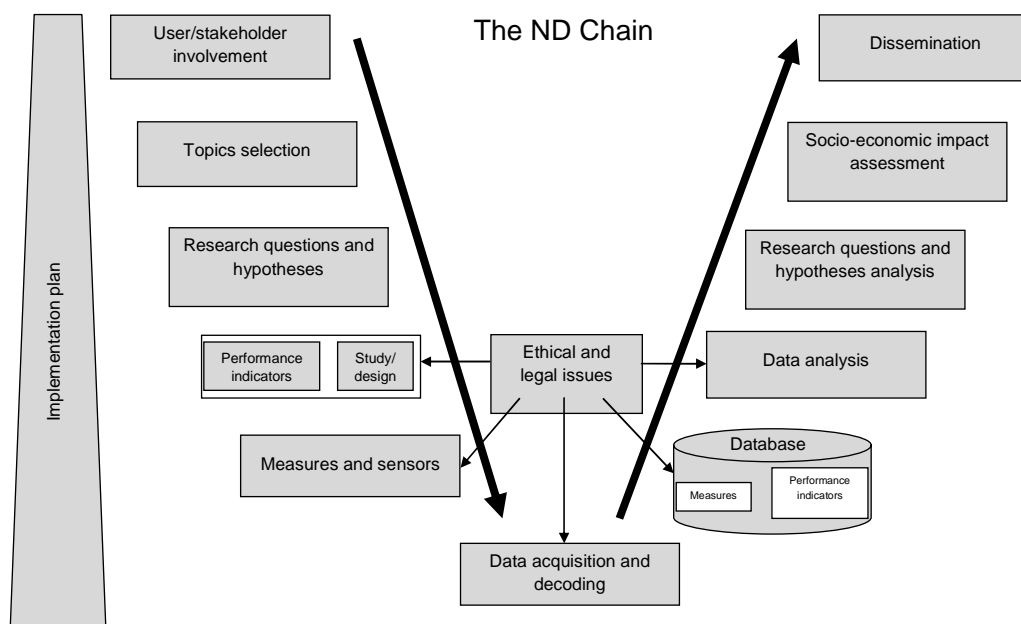


Figure 8.1 A tentative modification of the FESTA "V" to adapt it to ND studies

8.2 Research questions and stakeholder involvement

Some of the “big” questions that are particularly useful to address in a large-scale ND study are:

- How to get a 'full' picture of road safety; i.e., how to increase our understanding of driver behaviour and crash risk by integrating ND data with other data sources?
- How to understand the relationships between driver behaviour, near-crashes and crashes?
- What are the most important characteristics and determinants of distraction, inattention and fatigue?
- To what extent can advanced vehicles and advanced vehicle technologies result in behaviour adaptation or risk compensation that reduces the beneficial effects of measures intended to increase safety?
- How can considerations of safety, environment and mobility be integrated in naturalistic driving observations?

A large-scale ND study could also contribute to further methodological improvements in the field of traffic behaviour research, e.g. validation of alternative methods such as self-reported behaviour, validation of the ND method itself by investigating the possibility that drivers' consciousness of being observed influences their behaviour, and developing surrogate measures for crashes.

Finally, it is recommended that a large-scale ND study looks at the possibilities to use ND data for some practical applications, such as providing safety-related feedback to learner drivers, implementing and evaluating eco-driving courses, and monitoring safety performance indicators for statistical purposes.

It has been found that several stakeholder groups have interest in one or more research topics. A good dialogue with these potential user groups is important both for identifying the most urgent needs for knowledge and for getting support for carrying out a study that will result in useful results from both a short-term and long term perspective.

8.3 Study design and sampling

Given the different levels of methodological sophistication of available recording systems, there are several options for designing a large-scale naturalistic study. Briefly, the following alternative approaches can be differentiated:

- A study with the most advanced level of equipment and a large to moderate representative sample of drivers/vehicles.
- A study with less advanced equipment and a larger sample of drivers/vehicles.
- A study with basic driving parameters only and a very large sample of drivers using, for example, Smartphone technology.
- A series of smaller independent studies tailored to different research questions.
- A multi-level study with a very large total sample and different levels of equipment for different sub-samples.

From a cost-effectiveness point of view, the latter alternative seems to be the most realistic one.

Sampling of drivers and vehicles has to be based on the research questions to be investigated. However, it is recommended to design a large-scale study in such a way that it allows for investigating post hoc research questions in addition to pre-defined questions. Therefore, a combination of a large random sample and targeted samples for specific questions is recommended. If the study is supposed to be used for identifying crash predictors, a very large sample of drivers/vehicles and/or a long duration of the study is necessary, yielding a total exposure of several million vehicle kilometres.

8.4 Data collection, storage, analysis and much more

In addition to the issues presented in the previous sections, many more sometimes very specific considerations and decisions are required when planning a large-scale ND study. These include decisions related to the indicators of interest, the concrete variables to be measured, data collection issues, data storage, data analysis, and many more. For illustration and without the intention to be exhaustive:

For data collection and data storage, basic requirements include:

- Unobtrusive recording;
- Potential for continuous recording;
- Sufficient data storage capacity;
- Easy data transfer;
- Reliability against data loss;
- Reliable driver identification for every trip, with minimum effort of the driver;
- Data protection even in cases of crashes or intentional tampering.

For data analysis, important considerations include, among many others:

- Definitions of start and end of a trip;
- Inclusion of data quality check routines as an integrated part of any analysis;
- Investigation of possibilities for semi-automated analysis of video recordings, to make the analyses less time-consuming;
- Application of appropriate methods of statistical analysis.

Last but not least it must be realized that recording the behaviour of identifiable drivers raises several legal and ethical issues, in particular related to privacy protection.

8.5 In summary: PROLOGUE's 11

Conducting a large-scale ND study requires an almost infinite number of decisions and considerations, on all sorts of issues and at all levels. The PROLOGUE project, summarized in this final Deliverable, provides an overview of these issues and resulted in many recommendations on various levels of detail. The most important general recommendations have been summarized in eleven items, PROLOGUE's 11:

1. The European ND study should include pedestrians and (powered) two-wheelers (VRUs), and trucks, in addition to cars thus distinguishing it from the U.S. studies

2. An integrated data acquisition system is recommended because use of different technologies and vendors within the same project creates validation and data compatibility issues that lengthen the study and make it more expensive.
3. Difficulties associated with recruiting drivers, as experienced in the SHRP2 project, should be taken into consideration when planning the large-scale study, and should be addressed in the design and the timetable of the study.
4. In part of the study site-based and in-vehicle observations should be combined.
5. Some specific research questions should be stated, and the design should be geared to answering them. An example of a design adaptation to specific research questions is over-sampling of certain groups, like young drivers, old drivers, or new vehicles.
6. Automatic recording of behaviour should be supplemented by driver interviews e.g. to investigate look-but-did-not-see incidents with powered two-wheelers. The ND database should also be enriched by adding other driver background data like sensation seeking, Driver Behaviour Questionnaire, and past violations and crashes.
7. Emissions and on-line fuel consumption should be recorded for analysing eco-driving and environmental effects.
8. Route and lane preferences and their relationship to background variables should be observed in order to provide relevant data for traffic management purposes.
9. Inputs and/or insights from different stakeholders should be used to identify specific research questions.
10. Cultural differences in driving patterns should be investigated; this requires data about type, number and locations for different observation sites.
11. Some aspects of the data collection measures should be harmonized with those of SHRP2 and other large-scale naturalistic driving databases for the purpose of comparing European data with data from the U.S. and elsewhere and also for combining databases to get larger samples for analysing crash risk.

8.6 Further reading

Boyle, L. N., Lee, J. D., Neyens, D. M., McGehee, D. V., Hallmark, S., & Ward, N. J. (2009). *SHRP2 S02 Integration of analysis methods and development of analysis plan. Phase 1 Report*. University of Iowa, Iowa City, IA.

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Sagberg, F., Eenink, R., Hoedemaeker, M., Lotan, T., van Nes, N., Smokers, R., Welsh, R., Winkelbauer, M. (2011). *Recommendations for a large-scale European naturalistic driving observation study*. PROLOGUE Deliverable D4.1. TØI Institute of Transport Economics, Oslo, Norway.

Appendix I: Overview of main PROLOGUE Deliverables

The PROLOGUE project resulted in many Deliverables, both technical reports and dissemination products. This Appendix presents all public Deliverables ordered by work package/subject and subsequently by Deliverable number.

WP1: Potential application areas and users

Backer-Grøndahl, A., Phillips, R., Sagberg, F., Toulou, K., Gatscha, M. (2009). *Naturalistic driving observation: Topics and applications of previous and current naturalistic studies*. PROLOGUE Deliverable D1.1. TØI Institute of Transport Economics, Oslo, Norway.

Van Schagen, I., De Craen, S., Van Nes, N., Eenink, R. (2010). *The areas of interest of potential users for naturalistic observations studies*. PROLOGUE Deliverable D1.2. SWOV Institute for Road Safety Research, Leidschendam, The Netherlands.

Sagberg, F., Backer-Grøndahl, A. (2010). *A catalogue of applications and research topics for future naturalistic driving studies*. PROLOGUE Deliverable D1.3. TØI Institute of Transport Economics, Oslo, Norway.

WP2: Technical, methodological and organizational aspects

Welsh, R., Reed, S., Talbot, R., Morris, A. (2010). *Data collection, analysis methods and equipment for naturalistic studies and requirements for the different application areas*. PROLOGUE Deliverable D2.1. Loughborough University, Loughborough, UK.

Groenewoud, C., Schoen, E., Malone, K., Jonkers, E., Hoedemaeker, M., Hogema, J. (2010). *Methodological and organizational issues and requirements for ND studies*. PROLOGUE Deliverable D2.2. TNO, Soesterberg, The Netherlands.

WP3: Small-scale field trials

Lotan, T., Albert, G., Ben-Bassat, T., Ganor, D., Grimberg, E., Musicant, O., Hakkert, S. and Toledo T. (2010). *Potential benefits of in-vehicle systems for understanding driver behaviour; a series of small-scale ND studies in Israel*. PROLOGUE Deliverable D3.2. Or Yarak, Hod Hasharon, Israel

Christoph, M., Nes, N., Pauwelussen, J., Mansvelders, R., van der Horst, A.R.A., Hoedemaeker, M. (2010). *In-vehicle and site-based observations of cyclists; a small-scale ND field trial in the Netherlands*. PROLOGUE Deliverable D 3.4. TNO, Soesterberg, The Netherlands.

Gatscha, M., Brandstätter, C., Pripfl, J. (2010). *Video-based feedback for learner and novice drivers; a small-scale ND field trial in Austria*. PROLOGUE Deliverable D3.3. Test & Training International, Teesdorf bei Baden, Austria.

Valero-Mora, Pedro M., Tontsch, A., Pareja-Montoro, I., Sánchez-García, M. (2010). *Using a highly instrumented car for naturalistic driving research: a small-scale study in Spain*. PROLOGUE Deliverable D3.5. INTRAS/University of Valencia, Valencia, Spain.

Touliou, K., Margaritis, D. (2010). *Effects of Forward Collision and Lane Deviation Warnings on road user behaviour; a small-scale Naturalistic Driving study in Greece*. PROLOGUE Deliverable D3.6. CERTH/HIT, Thessaloniki, Greece.

Backer-Grøndahl, A., Lotan, T., Van Schagen, I. (2011). *Summary and integration of a series of Naturalistic Driving field trials*. PROLOGUE Deliverable D3.7. TØI Institute of Transport Economics, Oslo, Norway.

WP4: Recommendations for a large-scale Naturalistic Observation study

Sagberg, F., Eenink, R., Hoedemaeker, M., Lotan, T., van Nes, N., Smokers, R., Welsh, R., Winkelbauer, M. (2011). *Recommendations for a large-scale European naturalistic driving observation study*. PROLOGUE Deliverable D4.1. TØI Institute of Transport Economics, Oslo, Norway.

Van Schagen, I., Welsh, R., Backer-Grøndahl, A., Hoedemaeker, M., Lotan, T., Morris, A., Sagberg, F., Winkelbauer, M. (2011). *Towards a large-scale European Naturalistic Driving study: main findings of PROLOGUE*. PROLOGUE Deliverable D4.2. SWOV Institute for Road Safety Research, Leidschendam, The Netherlands.

WP5: Stakeholder involvement and dissemination of results

Eenink, R. (2010) *Composition of the PROLOGUE User Forum per February 2010*. PROLOGUE Deliverable D5.2. SWOV Institute for Road Safety Research, Leidschendam, The Netherlands.

Eichhorn, A., Winkelbauer, M. (2010) *1st PROLOGUE Workshop Minutes*. Deliverable D5.6. Kuratorium für Verkehrssicherheit KfV, Vienna, Austria.

Eichhorn, A. (2010). *Strategy and materials for regional workshops*. PROLOGUE Deliverable D5.8. Kuratorium für Verkehrssicherheit KfV, Vienna, Austria.

Eichhorn, A., Van Schagen, I. (eds.) (2011) *Minutes of six regional workshops about Naturalistic Driving*. PROLOGUE Deliverable D5.11. Kuratorium für Verkehrssicherheit KfV, Vienna, Austria

Eichhorn, A. (2011). *Final PROLOGUE Workshop Minutes*. PROLOGUE Deliverable D5.13. KfV Kuratorium für Verkehrssicherheit, Vienna, Austria.

As well as a website, several newsletters, brochures and a video

Appendix II: Matrix of potential research topics in ND research

Main sources: ¹ From SHRP2 S05; ² From SHRP2 S01; ³ From PROLOGUE D1.1

Driver-related	Driving condition	Examples of research topics or questions
Distraction and inattention	General research topic/question	Exposure to distraction. ³ Distraction contribution to accidents/incidents. ³ What is the relative risk of eyes off the forward road way? ¹ How do drivers process multiple sources of information? ¹
	Driver background factors and trip characteristics	What is the relationship between measures obtained from pre-test batteries (e.g. a life-stress test) and the frequency of engagement in distractive behaviours while driving? ¹ Young drivers and engagement in distractive activities. ³
	Road system, road environment, ambient conditions	To what degree do different types of distractions influence inattention at intersections? ¹ Distraction under different environmental conditions. ³ Engagement in secondary tasks under specific road environments (urban, rural, etc.). ³
	Vehicle design, equipment and condition.	In-vehicle systems and distraction. ³ Does type of car influence the likelihood of engaging in secondary tasks during driving?
	Interaction with other road users; traffic volume	What is the role of driver inattention in crashes involving pedestrian in travel lane? ¹ Engagement in secondary tasks under varying traffic volumes. ³
	Combination of two or more conditions	What external distractions influence driving behaviour (i.e., billboards, variable message signs, pedestrians, animals, objects, other traffic, etc.)? ¹
Fatigue, sleepiness, other impairments	General research topic/question	Behavioural measures of drowsiness. ³ Drowsiness contribution to crashes/incidents. ³
	Driver background factors and trip characteristics	Drowsiness among commercial vehicle drivers. ³ How often and under what circumstances do drivers drive while fatigued? ¹
	Road system, road environment, ambient conditions	Is falling asleep while driving more likely on monotonous roads? What is the relative contribution of impairment to red light running? ¹
	Vehicle design, equipment and condition.	Do advanced driver support systems offer a safety benefit for impaired/drowsy drivers? ¹
	Interaction with other road users; traffic volume	What is the role of driver fatigue in crashes involving pedestrian in travel lane? ¹
	Combination of two or more conditions	What is the incidence of drowsiness and conditions under which drowsiness arises? ¹

Driver-related	Driving condition	Examples of research topics or questions	
Decision making, errors, driving style/performance	General research topic/question	How do drivers make decisions? ¹ What is the driver reaction time and control input selection for safety-critical events? ¹	
	Driver background factors and trip characteristics	What is the role of inattention in intersection errors/conflicts? ¹ What are the behavioural characteristics especially in terms of driving style and visual search that distinguish young drivers and old drivers from the 25-65 year old drivers? ¹	
	Road system, road environment, ambient conditions	What are the safety effects of protected and unprotected turn lanes? ¹ Are drivers less likely to pass with centreline rumble strips? ¹	
	Vehicle design, equipment and condition.	Is the likelihood of driving errors related to the vehicle design? Is there an optimal design in order to minimise errors?	
	Interaction with other road users; traffic volume	How many times do drivers misjudge car acceleration/time available? ¹	
	Combination of two or more conditions	How does driver performance vary as a function of experience, road design, and/or traffic conditions?	
	Lane change and lane position and lane keeping	General research topic/question	Duration of lane changes. ³
		Driver background factors and trip characteristics	Lane change behaviour of different drivers. ³
		Road system, road environment, ambient conditions	What is the influence of super-elevation on lane-keeping and departure? ¹ How do lane-edge-markings affect lane-keeping? ²
Vehicle design, equipment and condition.		Signal use during lane changes. ³ Lane changes of different vehicles; e.g. light and heavy vehicles. ³	
Interaction with other road users; traffic volume		What is the influence of adjacent traffic or opposing traffic on lane keeping? ¹	
Combination of two or more conditions		What key driver, vehicle, roadway, and environmental factors affect lane keeping which may result in a road departure? ¹	

Driver-related	Driving condition	Examples of research topics or questions
Speed and acceleration	General research topic/question	How do drivers select speed? ¹
	Driver background factors and trip characteristics	How do drivers of various age categories use the available acceleration lanes when entering freeways? ¹ Is there a subset of drivers that are responsible for the majority of speeding or do all drivers speed occasionally? ¹
	Road system, road environment, ambient conditions	How do traffic control variables influence speed behaviour at intersections? ¹ How does pavement roughness affect speed? ¹
	Vehicle design, equipment and condition.	In-vehicle safety systems and risk compensation. ³
	Interaction with other road users; traffic volume	Do drivers travel at lower speeds and within what range when pedestrians (especially children) and bicyclists are present? ¹
	Combination of two or more conditions	What factors influence a driver's choice of operating speed – roadway geometry, roadside features, intersection/driveways, weather, traffic volume, day vs. night, etc.; and how does the speed change?
Gap acceptance, headway	General research topic/question	What is the relationship between gap acceptance, own speed and the speed of other vehicles?
	Driver background factors and trip characteristics	Do older drivers have higher thresholds for gap acceptance in intersections? ¹
	Road system, road environment, ambient conditions	How do traffic control variables influence gap acceptance at intersections? ² How does roadway design influence gap acceptance at intersections? ^{1,7}
	Vehicle design, equipment and condition.	Do vehicle characteristics (e.g. engine power) influence gap acceptance at intersections?
	Interaction with other road users; traffic volume	What is the role of following distance in crashes involving pedestrian in travel lane? ¹
	Combination of two or more conditions	Are there interactions between driver characteristics, vehicle characteristics, and/or road environment regarding gap acceptance at intersections or time headway to a lead vehicle?

Driver-related	Driving condition	Examples of research topics or questions
Aggressive driving; compliance with regulations	General research topic/question	How does aggressive driving behaviour impact crash or near crash risk? ¹
	Driver background factors and trip characteristics	What is the level of compliance by drivers of various age categories to stop signs, traffic signals, advisory speeds on curves, speed limits, stopping for pedestrians? ¹
	Road system, road environment, ambient conditions	What is the role of illegal manoeuvres in collision risk at intersections? ¹ How does roadway design influence compliance with traffic controls at intersections? ¹
	Vehicle design, equipment and condition.	Does the type of vehicle (e.g. SUV or sports vehicle compared with ordinary car) influence the likelihood of aggressive driving behaviour?
	Interaction with other road users; traffic volume	What is the role of aggressive driving as it relates to crashes involving pedestrians, objects, and animals in the travel lane?
	Combination of two or more conditions	Why do aggressive driving behaviours occur? ¹
	General research topic/question	How do different driving skills develop as a function of number, length and spacing of driving lessons?
Learning	Driver background factors and trip characteristics	Are effects of driver training dependent on driver background factors?
	Road system, road environment, ambient conditions	How does driver behaviour in different road and traffic conditions change during driver training or during the first phase of solo driving? Does a driver's familiarity with a road influence his driving behaviour? ¹
	Vehicle design, equipment and condition.	How do drivers come to use and understand advanced in-vehicle safety systems, and are the full benefits of the system being realized by individual drivers? ¹ What are the effects of learning to use new infotainment devices on driving performance? ¹
	Interaction with other road users; traffic volume	How do visual search skills and attention to other road users develop during driver training and during the first phase of solo driving?
	Combination of two or more conditions	How do driver, vehicle and environment factors influence speed choice in different phases of driver training and during the first phase of solo driving?
	General research topic/question	How do different driving skills develop as a function of number, length and spacing of driving lessons?
	Driver background factors and trip characteristics	Are effects of driver training dependent on driver background factors?

Driver-related	Driving condition	Examples of research topics or questions
Multiple behaviours/states, interactions	General research topic/question	How often do drivers interact with infotainment systems? ¹ Patterns of use of in-vehicle systems. ³ What is the relative contribution of impairment to inappropriate gap acceptance? ¹
	Driver background factors and trip characteristics	Young novice drivers' behaviour and involvement in incidents/accidents. ³ Elderly drivers' behaviour and involvement in incidents/accidents. ³ Route choice of young drivers. ³ Can various driver states (drowsy, aggressive, distracted, engaged) be identified from ND data? ² How does a driver's behaviour change with and without passengers in the vehicle? ¹
	Road system, road environment, ambient conditions	How do roadway features influence driver performance and behaviour? (SHRP2 S02 Global res. question)
	Vehicle design, equipment and condition.	Do the vehicle characteristics influence the crash likelihoods or driver behaviours? (SHRP2 S02, Global research question)
	Interaction with other road users; traffic volume	Interaction with heavy vehicles from light vehicle perspective. ³
	Combination of two or more conditions	Are there interactions between driver characteristics, vehicle characteristics, and/or road environment regarding frequency of risk-related driver behaviours?

Appendix III: Examples of variables to measure

Source: PROLOGUE D2.2. Variables in bold print are considered highly recommended

Table III-1: Demographic and personality variables

Stable variables (driver traits)	Unstable variables (driver states)
Age	Physical condition
Gender	Locus of control
Country of living	Self-reported driving behaviour (DBQ)
Education	Attitudes/intentions towards speeding, safety, environment
Income	
Aggressiveness	
Cognitive skills	
Risk perception	
Professional driver	
Driving experience (years, total kilometres, kilometres per year)	
Masculinity/femininity	
Field dependence	
Sensation seeking scale	

Table III-2: Driving behaviour variables

Driving behaviour variables
Frequency of performed left and right lane changes (number per kilometre and hour)
Frequency of active overtaking (number per kilometre and hour)
Frequency of passive overtaking (number per kilometre and hour)
Deviation from desired lane
Frequency of route changes (number per kilometre and hour)
Travel time uncertainty
Delay
Following/free state profile
Speed profile
Actual route
Use of car horn
System interaction and driving behaviour related responses to alarm/warning
Reaction time to alarm/warning

Table III-3: Driver distraction and state variables

Driver distraction and state variables
Mental workload
Fatigue/drowsiness
Distraction from primary driving task (eye-tracking, glance duration, fixation)
Head-tracking
Number and position of hands on steering wheel
Presence and use of in-car devices (e.g. mobile phone, navigation system etc)
Driver identified events
Presence, number and age of passengers
(moving) object inside vehicle
Performing tasks other than the primary driving task:
<ul style="list-style-type: none"> - eating/drinking - adjusting radio or other in-car device (e.g. climate controls, CD etc) - dialling or texting on mobile phone

Table III-4: Vehicle condition variables

Vehicle condition variables
Vehicle type (manufacturer, model, vehicle age)
Vehicle Identification Number (VIN)
Vehicle mass: driver + passengers, load besides driver and passengers, trailer connected or not, amount of fuel in the tank
Presence of safety systems (ACC, LDWS etc.)
Air conditioning: use/not use
Wiper status: use/not use
Other auxiliaries: use/not use
Cooling fan: operating/ not operating
Type of transmission
Type and amount of in-vehicle systems

Table III-5: Weather and light condition variables

Weather and light condition variables
Precipitation (i.e. snow, rain, fog)
Date; time of the day
Daylight/dark conditions
Air pressure (measured with vehicle sensor)
Air temperature (measured with vehicle sensor)
Humidity (measured with vehicle sensor)
Wind speed

Table III-6: Vehicle variables

Vehicle variables
Speed
Acceleration (longitudinal, lateral & gyro)
Deceleration (incl. sudden braking)
Percentage throttle
Percentage clutch
Percentage brake
Brake force
Gear position
Steering wheel angle
Turn signal
Lateral position
Lane departure
Time to line crossing (TLC)
Distance to vehicle in front
Distance to vehicle behind
Distance to other surrounding vehicles
Side vehicle detection
Time headway (forward & rear headway detection)
Space headway (forward & rear headway detection)
Time to collision (forward & rear TTC)
Post encroachment time (PET)
Travel time (including stop time)
Travel distance (mileage)
Waiting time at intersections
Friction

Table III-7: Traffic condition variables

Traffic condition variables
Traffic density
Speed distribution, average speed and standard deviation
Traffic composition
Traffic signal picture
Traffic flow
Other (unrelated) incidents that may affect traffic flow
Category of road users in vicinity (pedestrian, cyclist, light/heavy vehicle, etc)
Speed/acceleration of road users in vicinity
Behaviour of road users in vicinity

T

Table III-8: Road variables

Road variables
Road surface conditions (in Sweden by use of the winter model)
Road distance (a GPS will probably not have accuracy enough)
Road and traffic conditions based on GPS and time:
Gradient; horizontal curve; junction; roughness;
Macro texture
Road type
Environment (Urban/interurban/rural)
Number of lanes
Width of lanes
Base capacity and saturation flows
Central barrier
Sight distance
Speed limit
Location of speed cameras
Current traffic management: road markings, signs, rumble stripes, etc
Bus stops or parked cars along the street
Hard shoulder
Intersections:
<ul style="list-style-type: none"> - frequencies - intersections types (signals/roundabouts/yield/stop) - exit roads
Number of stops on route

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List of Abbreviations

ABS:	Anti-lock Braking System
ADAS:	Advanced Driver Assistance System
BLOB:	Binary Large Object
CAN(bus):	Controller Area Network
DAS:	Data Acquisition System
EU:	European Union
FCW:	Forward Collision Warning system
FOT:	Field Operational Test
GR system:	Green Road system
GIS:	Geographical Information System
GPS:	Global Positioning System
JPEG:	Joint Photographic Experts Group
LDW:	Lane Departure Warning system
ME system:	Mobileye system
ND:	Naturalistic Driving
OBD:	OnBoard Diagnostics
PET:	Post Encroachment Time
SAS:	Statistical Analysis System
SHRP2:	Strategic Highway Research Program 2
SPSS:	Statistical Package for the Social Sciences
SQL:	Structured Query Language
TTC:	Time to Collision
USB:	Universal Serial Bus
WP:	Work Package