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Recommendations for a large-scale European naturalistic driving observation study

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Abstract

Naturalistic driving observation is a relatively new research method using advanced technology for in-vehicle unobtrusive recording of driver (or rider) behaviour during ordinary driving in traffic. This method yields unprecedented knowledge primarily related to road safety, but also to environmentally friendly driving/riding and to traffic management. Distraction, inattention and sleepiness are examples of important safety-related topics where naturalistic driving is expected to provide great added value compared to traditional research methods.

In order to exploit the full benefits of the naturalistic driving approach it is recommended to carry out a large-scale European naturalistic driving study. The EU project PROLOGUE has investigated the feasibility and value of carrying out such a study, and the present deliverable summarises recommendations based on the PROLOGUE project.

A matrix of research topics and questions has been developed, based on categories of driver behaviour and states combined with various situational categories. The design of the large-scale study should be based on a selection of research questions judged to be particulary important for policymakers and other stakeholders. At the same time it should be acknowledged that the enormous amounts of data that can be collected in a naturalistic observation study can be used both for analysing predefined research questions and for post hoc investigations of new research questions.

In designing a large-scale study an optimal trade-off has to be sought between the sophistication of recording technology on the one hand, and the size of the driver sample and duration of the study on the other, since both highly sophisticated technology and a large database imply high project costs. The levels of recording technology may vary from basic driving parameters like speed, acceleration and position to a system including several video channels, eye-tracker and a multitude of vehicle parameters. An important purpose of naturalistic driving observations is to identify crash-related behaviour and to estimate the relative risks associated with those behaviours; in other words, to validate various crash proxies or crash surrogate measures to be used e.g. in subsequent monitoring of safety performance indicators. Since crashes are rare, this requires large samples and/or long duration of the study, amounting to several millions of vehicle kilometres. It has to be carefully considered which parameters are the most important to observe in such a large-scale study to capture the potentially most relevant crash-related behaviours. One possibility is to design a multi-level study, consisting of a very large sample with recording of basic driving parameters, a medium-size sample with some more advanced recording technology (e.g. trigger-based video to record pre-defined types of incidents) and a small sample with very advanced recording technology (including e.g. continuous video and eye-tracking).

When recruiting participants to the study, representativity as well as possibilities of investigating behaviours of particular groups of drivers must be considered. Other issues that need attention are personal privacy protection of both drivers and passengers, and participants' right to withdraw from the study. Monetary incentives as well as adequate procedures to avoid inconvenience to participants may be important measures for successful recruitment.

There are several important requirements to the data acquisition system, including reliability, ease of installation and deinstallation, and the possibiliity of transferring data effectively, without data loss, and without inconvenience for the participants.

Finally, adequate tools for data analysis are required, including good algorithms and procedures for identifying critical incidents and driver actions to be analysed.

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Executive Summary

Purpose and background

The purpose of this report is to present recommendations for carrying out a large-scale European research study of road safety and environmental effects of driver behaviour, as well as implications for traffic management, utilizing the recent technological development of methods for advanced naturalistic driving (ND) observations. The recommendations report is a part of the PROLOGUE project, which is financed by the European Commission under the 7th Framework Programme for research and development.

The PROLOGUE project is aimed at road transport researchers and other stakeholders including the car industry, insurance companies, driver training and certification organisations, road authorities, and governments. The main objective of PROLOGUE is to assess the value and feasibility of conducting a large-scale ND observation study in a European context.

The present deliverable is a discussion of recommendations for a large-scale European study, based on experiences from the previous work packages of the PROLOGUE project as well as on other recent or ongoing projects related to naturalistic driving observations. Recent methodological and technological advances are also considered.

For a European large-scale ND study, two types of studies serve as an inspiration. The first is the Strategic Highway Research Program 2 (SHRP2) in which a U.S. large-scale ND study is defined by the Transportation Research Board (TRB). This was preceded by the so-called 100-car study which allowed the TRB to compose a study design for the large-scale ND study including a large initial budget (Section 1.4.1). The European situation is essentially different, as will be explained in this report, which means that composing a similar study design is not an option. The second inspiration is the developments within Field Operational Tests (FOT). The purpose of an FOT is to evaluate measures or technologies (usually in-car) in their final stage of development on a large scale, in which naturalistic driving observation is often part of the evaluation. For setting up and running FOTs a handbook was produced in the FESTA project (Section 1.4.2). The purpose of ND is to gain general insight in driver behaviour which is essentially different and less focused. Therefore, making an "ND handbook" was not the aim of PROLOGUE, although a first idea is presented in Section 1.4, and the EU FOT-NET2 project is working on a revision of the FESTA handbook which will include adaptation to ND research.

The discussion of recommendations includes all phases of conducting a large-scale naturalistic driving observation study, i.e., definitions of scope and purpose and added value, identification of applications, research questions and hypotheses to be investigated, procedures for selecting driver and vehicle samples, requirements to recording equipment, procedures for data collection, transfer and analysis. Ethical, legal, and personal privacy issues are discussed as well.

ND studies imply unobtrusive recording of behaviour of drivers driving their own cars under ordinary traffic conditions, by means of advanced recording equipment that is mostly concealed from the driver's view. This approach makes it possible to derive knowledge about safety-related and other behaviour in real traffic, which is impossible or difficult to obtain by more traditional research methods. Some typical parameters that are recorded include vehicle speed and acceleration, activation of vehicle controls (braking, steering, gear shift, accelerator, etc.), status of displays and indicators, video recordings (primarily driver face and forward traffic scene), as well as GPS coordinates.

Until recently, studies involving direct observation of driver behaviour, using video recordings of driver and roadway, and also saving vehicle data, have been mostly limited to experimentally controlled studies using specially equipped vehicles ("instrumented cars") driven by specially selected research participants, usually with an observer in the car, and often under more or less standardized driving conditions.

The ND approach can be considered as moving the driver and vehicle recording equipment from the experimental instrumented vehicles into ordinary vehicles in normal traffic, and removing the observer. This has become possible due to a technological development in the direction of smaller, more efficient and less expensive recording equipment, allowing relatively *unobtrusive* and continuous recording of driver behaviour as well as vehicle and road environment parameters.

Although road safety is the main field that is supposed to benefit from the ND approach, there are two additional issues that will be addressed to some extent. First, ND may yield knowledge about driving style and driving pattern, which may be relevant for understanding factors influencing environmentally-friendly driving ("eco-driving"), as a basis for finding measures to promote such driving. Second, and related to the environmental aspect, is the issue of mobility and traffic flow; for example, studying factors that can influence route choice, travel distances and speeds.

A large-scale European study is expected to add significantly to the knowledge provided by the few previous ND studies that have been conducted. The added value can be summarised 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

In addition, the study is expected to imply important advances in methods for driver behaviour observation:

- Combining in-vehicle and site-based road user observation methods
- Using the most advanced technology for unobtrusive driver behaviour observation

The previous work packages in Prologue, which form part of the input to the recommendations, include:

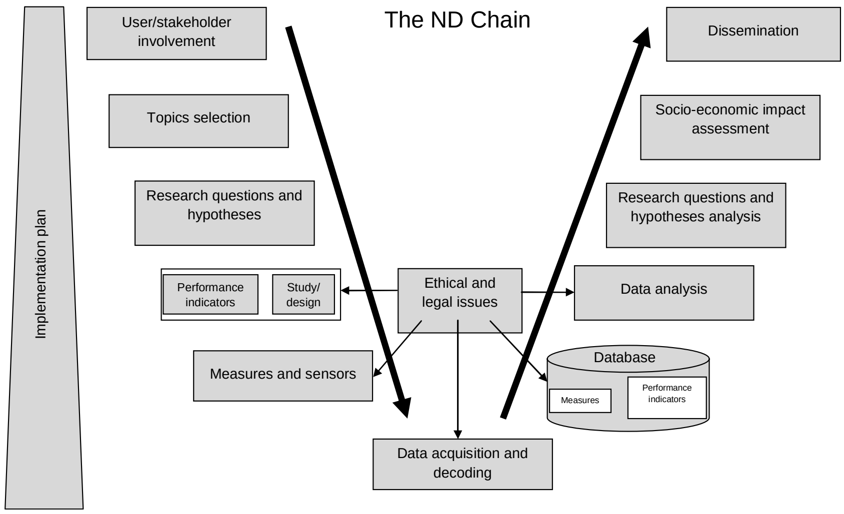
- A review of previous and ongoing ND and ND related studies.
- A survey among stakeholders regarding their interest in ND research.
- A catalogue of topics and questions for ND research and applications.
- An overview of methodological and organizational issues related to ND studies.
- A discussion of methods and equipment for collection and analysis of ND data.
- Small-scale field trials in five different countries. The trials used different methodological approaches, part of which can be considered real ND observations, whereas others used instrumented vehicles in a more or less naturalistic way.

In addition, there were both pan-European and regional workshops, with participation of representatives from several stakeholder groups.

Recommendations

General recommendations

For the overall planning of a study, the FESTA “V” may be a useful tool. It is developed as an implementation plan for FOT studies. In PROLOGUE we have modified it slightly and adapted it to ND research. The modified version – the ND “V” is shown in the figure below. The left-hand side of the V shows the various phases in preparing an ND study, and the right-hand side shows the phases related to data analysis and dissemination.



A tentative modification of the FESTA “V” (FESTA Consortium, 2008) to adapt it to ND studies

Naturalistic driving studies vary with respect to several methodological aspects, such as e.g. sophistication of data recording and size and composition of driver samples. Important parameters are: 1) variables to be recorded, 2) size of sample and duration of study, and 3) special requirements to sample composition as related to the research questions addressed in the respective studies.

Finally, any large-scale ND study must be preceded by a pilot study to check all equipment and procedures, in order to assure high data quality and reduce the risk of data loss.

Research topics and questions

Some of the “big” questions that could be answered by a large-scale ND study are:

- How do we get the “full” picture; i.e., how can we increase our understanding of driver behaviour and crash risk by integrating ND data with other data sources?
- How can we 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?

In the PROLOGUE project a matrix for defining categories of research questions was developed. The first step is a list of eight categories of driving behaviours and states that are considered particularly relevant for investigation by the ND approach. The second step is a list of four categories for various conditions under which those behaviours and states can be observed (or inferred). Finally, the driver-related categories and the conditions/background categories are combined in a matrix. This matrix is recommended as a tool for identifying and specifying research topics to be investigated by a naturalistic driving study.

The following categories of driver behaviour and driver states were listed:

- Distraction and inattention
- Fatigue, sleepiness and other acute impairments
- Decision-making, driving errors, driving style, and general driving performance
- Lane change and lane position
- Speed and acceleration
- Gap acceptance
- Aggressive driving
- Learning

The following situational categories were listed:

- Driver background factors and trip characteristics
- Road system, road environment, ambient conditions
- Vehicle design, equipment and condition
- Traffic volume and composition – interaction with other road users

Based on the combinations of these two dimensions, behaviour-related research topics related to either road safety, traffic management, or environmental effects can be defined.

A large-scale study should provide data that can be used for investigating any of the global research topics identified by the PROLOGUE matrix. Within each global research topic, specific research questions and hypothesis should be formulated.

One example of a more specific research question could be “Is falling asleep while driving more likely on monotonous roads?”, which belongs to the cell formed by the driver-related category “Fatigue, sleepiness, other impairments” and the driving condition category “Road system, road environment, ambient conditions”. A second example is “Do drivers travel at lower speeds when pedestrians (especially children) or bicyclists are present?”, which belongs to the cell formed by the categories “Speed and acceleration” and “Interaction with other road users; traffic volume”.

Within the road safety field, investigation of behaviour in incidents, near-crashes and crashes is an important purpose of ND research. Data from an ND study will allow us to quantify the crash risk associated with various driver, vehicle, road, and environmental factors, and to identify relevant behavioural indicators that can be used as crash surrogate measures. Identification of incidents and near crashes on the basis of the recorded data is, however, a difficult methodological challenge. Experiences from

PROLOUE field trials and other studies show that kinematic triggers (recordings of *g* forces) alone are not sufficient for reliable identification of incidents and near-crashes (i.e. close encounters where the ND driver fails to react at all, and a crash is avoided because of actions by some other road user). False alarms were also a problem in the field studies. Therefore additional video recording is important for validation of events identified by kinematic triggers.

A question related to environmentally friendly driving, is that of effective traffic management and minimization of travel time, since reduced travel time generally means lower energy consumption and less emission. There is clearly a need of more research in this field, focusing also for example on drivers' route choice in relation to travel time. Conceivably, naturalistic driving data may be applied to micro simulation for traffic management and strategic road network planning.

A possible topic which can be investigated by the ND approach is energy-saving driving behaviour, and the various conditions influencing such behaviour. "Eco-driving" or "green driving" denotes a smart and smooth driving style that is assumed to reduce fuel consumption and greenhouse emissions. Although some aspects of driving behaviour related to eco-driving have been measured in previous studies, there is a need for more comprehensive ND studies in order to understand the factors that may contribute to environmentally friendly driving. Another aspect that should be mentioned in the context of eco driving at the strategic level is 'trip planning', e.g. combining trips, using less congested hours, etc.

In addition to investigating specific research questions and hypotheses, the ND approach can contribute to further methodological improvements within the driver behaviour field, particularly in relation to road safety. More particularly, this may include:

- Validation of alternative methods, like self-reported behaviour
- Validation of other methods for accident reconstruction
- Validation of the ND method itself by investigating possible observer effects; i.e. the possibility that the drivers' consciousness of being observed may influence their behaviour
- Cross-validation of site-based and vehicle-based observations
- Developing surrogate measures for crashes

These methodological issues should be addressed in the large-scale study.

In addition to research, ND methodology may be used for some practical applications, like:

- Providing feedback (e.g. to learner drivers)
- Eco-driving courses
- Courses for elderly drivers
- Collecting data for potential in-depth accident investigations in commercial driving
- Using in-vehicle recording systems to make drivers refrain from risky behaviour
- Monitoring safety performance indicators for statistical purposes

It is recommended that some of these applications are investigated in conjunction with the large-scale study.

Stakeholder involvement

Several stakeholder groups have interest in various research topics that are addressed in ND studies, and an important part of the planning phase of a large-scale study is to identify the various stakeholder groups and to develop their involvement.

The following stakeholder groups and their respective interests in ND results were identified in the PROLOGUE project:

- Insurance companies: Crash and injury risk related to various risk factors, road user groups, and road and traffic conditions.
- Automotive industry: Safety and injury reduction; Driver interaction with IVIS and ADAS; Driver operation; Human-Machine Interface, Powered two-wheelers; Eco-driving.
- Public administration: Road-related risk factors; Effects of countermeasures; Monitoring of safety performance indicators; Traffic management; Vehicle emissions and fuel economy.
- Research institutions: All research topics.
- Driver training and licensing agencies: Development and learning of driving skills.
- The legal system: Objective data from crashes; Knowledge of normal variability of driving behaviour.
- Other stakeholders: Road user and consumer organisations may be interested in effects and usefulness of various road safety measures, and in risk factors.

The various stakeholder groups should be involved in an early stage in the panning of a large-scale study. A good dialogue with various 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 in both a short-term and long term perspective.

Study design

Considering 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 size 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 e.g. 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. An option for a large-scale study could be a design with different levels of technological sophistication for different sub-samples. A very large sample of vehicles (several thousands) could be equipped with relatively simple technology for recording basic driving parameters. This could be achieved by using smartphones, including GPS, accelerometer and video. Relatively simple technology would be sufficient e.g. for the purpose of long-term monitoring of road exposure data and safety performance indicators.

For sub-samples recording of basic driving parameters could be supplemented by trigger-based recording of driver and forward video as well as additional vehicle parameters, e.g. from the CAN-bus, in order to record predefined incidents.

For investigating specific research questions additional dedicated equipment could be added for smaller sub-samples. For example, eye-tracking and high-resolution video would be relevant for investigating driver visual search as well as distraction and inattention. And recording fuel consumption may be relevant only for studying environmental effects and not for safety; consequently the relevant parameters for this topic could be included for a smaller sub-sample only.

Indicators and measures

In order to assess the various research questions, relevant performance indicators have to be defined, based on the following categories of measures:

- Driver- based measures, e.g. video of the driver; physiological activity; speech
- Vehicle-based measures, e.g. status of indicators and controls (derived from CAN-bus)
- Environmental, situational and infrastructure measures: e.g. road type and condition; weather; traffic situation

The selection of measures has to be based on the research questions and the related performance indicators that have to be derived in order to investigate these questions.

A few examples will show how measures are related to indicators and how the indicators can be used for analysing research topics.

- Indicators derived from driver video may include head movements or eyeblinks for studying fatigue, inattention/distraction or visual behaviour. In combination with forward video, the eye video may also be used to derive indicators of visual fixation.
- An indicator based on gear position could be frequency and timing of gear changes (e.g. in relation to engine speed and load), for analyses of eco-driving.
- Distance to the vehicle in front, in combination with speed, may be used to define an indicator of tail-gating, e.g. time gap below a certain threshold. This may be related to research on aggressive driving.

Data acquisition

The technical system for in-vehicle recording is referred to as the DAS ("Data Acquisition System"), and the following groups of recording equipment are fundamental elements of a DAS that is to be used for ND observation studies:

- Interface to vehicle data (CAN-bus etc); minimum is speed and acceleration (lateral, longitudinal, vertical)
- GPS-based system for continuous storage of position
- Video cameras (minimum is forward view, driver, and rear view)
- Time code synchronization between all data channels

Basic requirements to the equipment include:

- Unobtrusive recording
- Potential for continuous recording

- Sufficient data storage capacity
- Easy data transfer
- Reliability against data loss
- Reliable system for driver identification for every trip, with a minimum of effort on the part of the driver
- Data protection even in cases of crashes or intentional tampering

Some additional desirable features of the DAS should also be mentioned:

- The system should preferably be integrated, so that all parts of the system are synchronized and data are saved to a common storage system
- Installation and de-installation should be as easy and flexible as possible; including the possibility of removal of components for repair
- Video image resolution should be sufficient for allowing identification of objects in the traffic environment, such as signs etc.

Possibilities for sound recording should be available (provided that contents of conversations can be masked for privacy protection); both occurrence of conversation in the vehicle, voice level, and engine sound may be important variables.

When combining in-vehicle and site-based recordings it is important to have systems for synchronizing the two sources of observation.

Driver/vehicle sampling

Sampling of drivers and vehicles has to be determined by the research questions to be investigated. However, a large-scale study should be designed for providing possibilities for investigating post hoc research questions in addition to pre-defined questions and hypotheses. 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.

Some benefits to participating drivers must be provided. A time-based compensation plus a bonus at the end (to prevent dropout) seems to be an effective incentive. A pool of “standby” participants should be recruited for quick replacement of drivers who quit.

The sample should be biased towards newer vehicles, in order that research findings related to vehicle technology are relevant to the vehicle fleet for a longer period after data collection.

Ethical and legal issues; privacy protection

Recording the behaviour of identifiable drivers raises several issues related to privacy protection. Signing an informed consent form is always necessary for participants in such a research study, and it is important that the potential participants are given all relevant information before signing the form. Furthermore, drivers shall have the right to withdraw from the study at any time and to require that recordings from their vehicle are deleted. If data can be made available to third-parties, e.g. for legal prosecution in the case of violations or crashes, participants must be informed. Since in-vehicle video recording is an essential part of ND studies, passenger privacy protection should be given particular attention. Informed consent from all participating drivers is a necessary requirement in such a study; and if passenger behaviour is recorded, consent from them is needed as well.

Data analysis

In the data analysis phase, the following considerations are important:

- Definitions of start and end of a trip have to be established.
- Routines for data quality check have to be an integrated part of any analysis.
- A taxonomy of accidents and incidents must be developed, based on the recorded measures. Discrete events to be investigated have to be defined.
- A taxonomy of behaviour must be developed, with operational definitions of essential concepts like inattention, distraction, fatigue, sleepiness, etc.
- Possibilities of semi-automated analysis of video recordings should be investigated, to make the analyses less time-consuming.
- Appropriate methods of statistical analysis should be applied.

The original database from the in-vehicle observations should be enriched by information from other relevant sources, such as information about driver background, vehicle characteristics, road infrastructure, or traffic conditions. Such data may be matched to the original database by time or position codes or by driver or vehicle identification codes.

Procedures for managing the database and for regulating access to the data have to be established.

Summary of recommendations

The most important general recommendations from the PROLOGUE project can be summarised in the following 11 items:

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 Overall purpose, background, scope, and importance

1.1 Purpose and scope

For a European large-scale naturalistic driving (ND) observation study two types of studies serve as an inspiration. The first is the Strategic Highway Research Program 2 (SHRP2) in which a U.S. large-scale ND study is defined by the Transportation Research Board (TRB). This was preceded by the so-called 100-car study which allowed the TRB to compose a study design for the large-scale ND study including a large initial budget (see Section 1.4.1). The European situation is essentially different, as will be explained in this report, which means that composing a similar study design is not an option. The second inspiration involves developments within Field Operational Tests (FOT). The purpose of a FOT is to evaluate measures or technologies (usually in-car) in their final stage of development on a large scale, which is similar to ND in terms of the type of recording equipment used and driver behaviour measures observed. For setting up and running FOTs a handbook was produced in the FESTA project (see Section 1.4.2). The purpose of ND is to gain general insight into driver behaviour which is essentially different and less focused on evaluating a particular system. Therefore, making a "ND handbook" was not the aim of PROLOGUE, although a first idea is presented in Section 1.4, and the EU FOT-NET2 project is currently working on an ND handbook.

The purpose of this report is to present recommendations for carrying out a large-scale European research study of driver behaviour and its possible environmental and road safety effects as well as implications for traffic management, utilizing the recent technological development of methods for advanced naturalistic driving (ND) observations. The recommendations report is a part of the PROLOGUE project, which is funded by the European Commission under the 7th Framework Programme for research and development with additional national funding from the participating countries. The report is mainly based on previous deliverables from the PROLOGUE project, but additional sources of research literature have been used as well.

In this chapter we will first describe the ND approach and give some examples of recommendations based on such studies. Next, we will point out its added value compared to traditional methods for driver behaviour and road safety research. In the following chapters recommendations for the various aspects of a large-scale European ND study will be discussed.

It will be shown that the ND method has unique contributions to the knowledge of driver behaviour, primarily in relation to road safety, but also regarding environmental effects and traffic flow. Carrying out a large-scale European study with this approach will provide a unique knowledge base, which will be useful to a wide range of stakeholders, such as road authorities, driver training and licensing bodies, road user organisations, vehicle industry, police, insurance companies, politicians, administrators, and others.

1.2 General description of the naturalistic driving observation method

There has been a long history of road safety research focusing on studying driver behaviour in traffic as knowledge about driver behaviour has been considered an important prerequisite for understanding the mechanisms of accident causation. Until recently, studies involving direct observation of driver behaviour, using video recordings of driver and roadway, and also saving vehicle data, have been mostly limited to experimentally controlled studies using specially equipped vehicles ("instrumented vehicles") driven by specially selected research participants, usually with an observer in the car and often under more or less standardized driving conditions. Such studies have obviously contributed greatly to increasing the knowledge about risk-related driver behaviour, and they have thus been a useful supplement to other types of behavioural studies, such as self-reports, analyses of crash statistics, in-depth crash studies, and simulator studies. The limitation, however, is that the drivers are observed under more or less artificial driving conditions, which precludes the possibility of getting information about many important safety-critical behaviours that may occur during normal driving.

The ND approach can be considered as moving the driver and vehicle recording equipment from the experimental instrumented vehicles into ordinary vehicles in normal traffic, and removing the observer. This has become possible due to a technological development in the direction of smaller, more efficient and less expensive recording equipment, allowing relatively *unobtrusive* and continuous recording of driver behaviour as well as vehicle and road environment parameters. Thus, the drivers may be observed during ordinary driving conditions. Although the equipment (including the video cameras) can be concealed from the view of the drivers, the drivers' awareness that their driving is being recorded may possibly influence their behaviour. This is of course a limitation, but there are indications that as drivers get used to driving with ND recording equipment, they tend to forget about being observed rather quickly. Even if there is a certain observer effect, such studies extend immensely the possibilities of direct behaviour observation under more naturalistic conditions than any other research method, and thus enable investigation of risk-related behaviours that until now have been studied only indirectly, yielding highly uncertain results.

A very important aspect of the ND approach is the inclusion of continuous GPS data, enabling subsequent detailed reconstruction of the vehicle's path of travel, as well as matching observations to a wide range of additional data sources containing GPS location coordinates.

For a more detailed discussion and comparison of ND with other research methods we refer to PROLOGUE deliverable D1.1 (Backer-Grøndahl et al., 2010).

Although road safety is the main field that is supposed to benefit from the ND approach, there are two additional issues that will be addressed to some extent. First, ND studies may yield knowledge about driving style and driving pattern, which may be relevant for understanding factors influencing environmentally-friendly driving ("eco-driving"), as a basis for finding measures to promote such driving. Second, and related to the environmental aspect, is the issue of mobility and traffic flow; for example, studying factors that can influence route choice, travel distances and speeds.

There is no clear-cut difference between ND studies and studies using traditional instrumented cars. For example, in some studies using instrumented vehicles, drivers have been driving in normal traffic and without an observer, which makes the situation more similar to the ND approach. It should also be mentioned that one type of method which is similar to the ND approach is the FOT ("Field Operational Test"), which involves the use of an instrumented vehicle in order to assess a particular piece of in-car equipment. This is usually done as part of the product development process, and may involve installing the particular equipment in a sample of ordinary cars for testing by volunteer drivers. Depending on the additional equipment of those vehicles, the FOTs may also yield data about driver behaviour that are comparable to the data from ND studies. An example of a recent large-scale FOT is the EU-funded EuroFOT project (*http://www.eurofot-ip.eu/en/welcome_to_eurofot.htm*), focusing on assessment of eight different driver assistance functions in a sample of more than one thousand drivers/vehicles. Even though there may be differences in purpose between ND and FOT studies, the technology for driver behaviour observation may be the same, and consequently experiences from FOTs are important inputs to the planning of a large-scale European ND study.

Since there are gradual transitions between the FOTs and ND studies, there is a need for defining ND. For the present report we have chosen to define the ND approach as research or applications sharing the following characteristics:

- Unobtrusive recording of driver and vehicle parameters
- Normal driving, i.e. driving purpose and driving destinations as defined by the driver, and driving taking place on roads open to ordinary traffic, and with the vehicle that the driver normally uses (owned, leased, or company vehicle)
- No observer present in the vehicle[1]

These criteria can be summarised in the following formal definition:

> A naturalistic driving study is 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.

Some typical parameters that are recorded include vehicle speed and acceleration, activation of vehicle controls (braking, steering, gear shift, accelerator, etc.), status of displays and indicators, video recordings (primarily driver face and forward traffic scene), as well as GPS coordinates. Eyetracking (visual fixation) is an interesting additional variable, especially regarding studies of inattention and distraction as well as driver visual search behaviour. Although visual fixation is still difficult to measure unobtrusively and with sufficient precision, technological advances may make this easier in the near future.

The similarity between FOTs and ND studies is further evidenced by the fact that an FOT may provide naturalistic observations of general driving behaviour in addition to the specific responses to the system(s) that are being evaluated in the FOT. Thus, it may make sense to talk about "naturalistic FOTs" to describe the type of study that is a combination of an FOT and an ND observation study.

1.3 The field trials and other previous work in PROLOGUE

An important background for the present report is the output from the previous parts of the PROLOGUE project. These include:

- A review of previous and ongoing ND and ND related studies (Backer-Grøndahl et al., 2010).
- A survey among stakeholders regarding their interest in ND research (van Schagen et al., 2010).
- A catalogue of topics and questions for ND research and applications (Sagberg and Backer-Grøndahl, 2010).
- An overview of methodological and organizational issues related to ND studies (Groenewoud et al., 2010).
- A discussion of methods and equipment for collection and analysis of ND data (Welsh et al., 2010).
- Small-scale field trials in five different countries (Backer-Grøndahl et al., 2011).

[1] An exception to this is when ND is used during driver training with an instructor.

- Pan-European and regional workshops, with participation of representatives from several stakeholder groups (Eichhorn & Van Schagen, 2011).

Regarding the field trials, one of the aims 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. Technology varied from a relatively simple g-force based data acquisition system to fully instrumented cars. Some of the trials applied a pure naturalistic approach, i.e. just having the participants drive for some period of time and then analyze 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 can be considered an example of a naturalistic FOT.

1.4 Previous recommendations for ND research

In addition to experiences from the PROLOGUE project itself, the present recommendations for a large-scale European study are based partly on previous general recommendations for ND or FOT studies. The following sources are considered particularly relevant:

- The “100-car study” and the SHRP2 project in the US
- The FESTA project and the FESTA handbook

Recommendations from these sources are summarized below.

1.4.1 ND studies in the US

1.4.1.1 The “100-car naturalistic driving study”

The description of the 100-car study is based on the report by Dingus et al. (2006).

One hundred drivers who commuted on a regular basis in the Northern Virginia and Washington D.C. metropolitan area were recruited to the study. Seventy-eight drivers drove their own car, whereas 22 drivers used leased cars. All cars were instrumented, and data were collected over an 18-month period. All vehicles were instrumented with a package engineered by Virginia Tech Transportation Institution (VTTI). The instrumentation included the following: a vehicle network box that interacted with the vehicle network, an accelerometer box obtaining longitudinal and lateral kinematic information, a headway detection system providing information on leading or following vehicles, side obstacle detection to detect lateral conflicts, incident box, video-based lane-tracking system and video to validate any sensor-based findings. The video-equipment consisted of 5 cameras monitoring the driver’s face and driver side of the vehicle, the forward view, the rear view, the passenger side, and a view of the driver’s hands and surrounding areas.

The data set included approximately 3.2 million vehicle-kilometres and 43,000 hours of data gathered over a period of 12-13 months for each vehicle. This research effort was initiated to provide an unprecedented level of detail concerning driver performance, behaviour, environment, driving context and other factors that were associated with critical incidents, near crashes and crashes. A primary goal was to provide vital exposure and pre-crash data necessary for understanding causes of crashes, supporting the development and refinement of crash avoidance countermeasures, and estimating the potential of these countermeasures to reduce crashes and their consequences.

The 100-car study was considered an "exploratory study to determine the feasibility, value, and methods for initiating a larger, more representative study" (Neale et al., 2005). Based on the experiences from the 100-car study, the SHRP2 naturalistic driving study described below was initiated.

Recommendations related to the various phases of conducting a large-scale study, based on lessons learned from the 100-car study, will be included in the following chapters.

1.4.1.2 The SHRP2 project

The description of the SHRP2 project is based on the report by Campbell and Mason (2008) and information from the project website (*http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/Public/Blank2.aspx*).

A large-scale naturalistic driving study is included as a part of the ongoing US Strategic Highway Research Program 2 (SHRP2). The in-vehicle driving behaviour study is conducted with volunteers driving instrumented vehicles for everyday use. An instrumentation package has been developed for installation on many vehicle models. The drivers use their own vehicles during the study period. The driver and vehicle pool will change at least once a year through the reinstallation of the instrumentation package in a new driver's vehicle.

The data collection package accommodates requirements for a variety of analyses of lane departure, intersection crashes, and other questions. The study is conducted in several geographic areas to accommodate variations in weather, geographical features, and rural, suburban, and urban land use. Data are archived for analysis as part of the data processing and will be made available to qualified researchers. Another critical need in the in-vehicle study of driving behaviour is for detailed roadway data, with greater coverage of the roads used by the volunteer drivers. These data will support the association of driver behaviour with roadway characteristics such as grade, curvature, and posted speed limits.

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

Since the project is still ongoing, there are no publications of recommendations or lessons learned yet. There are, however, reports of the procedure for development and prioritization of research questions (see e.g. Boyle et al., 2009), which will be used as an important source for the present recommendations regarding research topics in Chapter 2.

1.4.2 The FESTA Handbook and the FESTA "V"

1.4.2.1 The FESTA project

The FESTA Handbook (FESTA Consortium, 2008) is a guideline for planning, conduction, and analysis of FOTs. It is the main output from the EU project FESTA ("Field operational test support action"). Although its focus is on FOTs, there are large methodological overlaps with ND studies, and many of the recommendation are directly relevant for ND studies as well. (For a discussion on similarities and differences between FOTs and ND studies we refer to Section 1.2 above.)

Both the FESTA Handbook and other deliverables from the FESTA project are important sources for the present document.

1.4.2.2 Examples of FESTA recommendations

The FESTA Handbook specifies several activities that are necessary for conducting an FOT study. The following list is slightly adapted to be suited to ND studies in general:

- Convene teams and people
- Define aims, objectives, research questions and hypotheses
- Develop project management plan
- Implement procedures for stakeholder communication
- Design the study
- Identify and resolve legal and ethical issues
- Select and obtain vehicles
- Select and obtain data collection and transfer systems
- Select and obtain support systems
- Implement driver feedback and reporting systems
- Select/implement relational database for storing data
- Test all systems to be used according to specifications
- Develop recruitment strategy and material
- Develop driver training and briefing material
- Pilot test equipment, methods and procedures
- Collect data
- Analyse data
- Write minutes and reports
- Disseminate findings

The main steps were summarised in the FESTA “V” or FOT Chain (Figure 1.1).

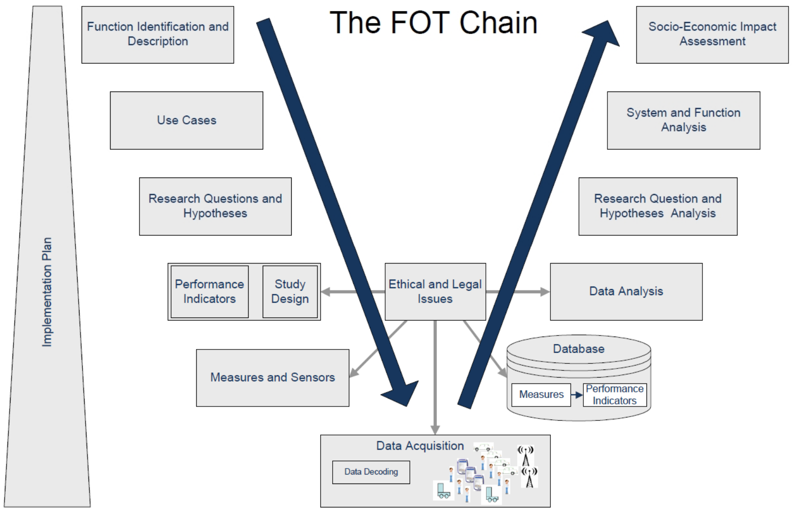


Figure 1.1 The FESTA "V" (The FOT Chain) showing the steps that typically have to be considered when conducting an FOT (Source: FESTA Consortium, 2008).

An important aspect of this figure is that there are corresponding phases before and after the data acquisition phase (the tip of the V). 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. Although this is a tool made for FOT studies, it is clearly relevant for ND research as well.

In the ongoing project FOT-NET 2 the FESTA methodology is being revised and adapted to ND studies in addition to FOTs. In order to convert the "FESTA V" into an "ND V" one could for example replace the box "Function identification..." on the downward slope of the V by "User/stakeholder involvement", and the second box "Use cases" by "Topics selection". On the upward part "System and function analysis" could be skipped and on the top an extra "Dissemination" could be added. Based on these suggested modifications, a tentative sketch of a new "ND Chain" is shown in Figure 1.2.

More specific recommendations related to the various phases of the study, will be mentioned in the following chapters.

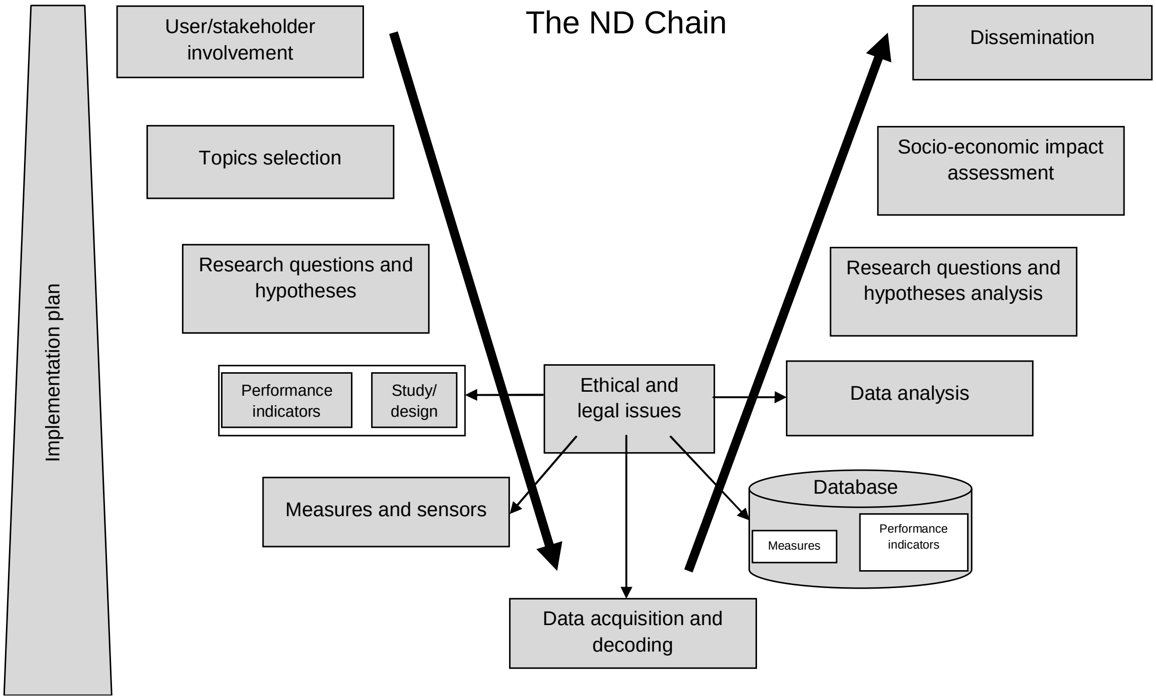


Figure 1.2 A tentative modification of the FESTA "V" (FESTA Consortium, 2008) to adapt it to ND studies.

1.5 The need for a large-scale European study

Compared to previous results from similar studies, the European large-scale study is expected to yield several additional benefits, such as:

- Gain better understanding of how and *why* crashes happen
- Create a multi-dimensional presentation and monitoring of road user behaviour and integrating it to derive the above
- A sufficiently large database to enable estimations of relative risk associated with different driver behaviours, and the validation of crash-related behaviour indicators
- Comparisons between different geographical areas with different driving cultures and traffic regulations
- A stronger focus on environmental aspects of driving (in addition to road safety)
- Including studies of vulnerable road users
- Combining in-vehicle with site-based naturalistic observation
- Benefit from recent technological development of recording equipment
- Input to traffic planning and traffic management, featuring typical European driver, road and vehicle characteristics

1.5.1 A large database for analysing crashes and crash-related behaviour

An important and methodologically unique feature of the ND approach is to compare driving behaviour during crashes and crash-related events with behaviour in near-crashes and normal driving. There are two types of analyses that can be done with this kind of data. Firstly, comparisons of driver actions between crashes and baseline conditions can be used to estimate the relative crash risk associated with certain actions and circumstances. Secondly, comparisons between crashes and near-crashes can be used for validation of performance indicators. In other words, hypotheses about relationships between driver actions and crash risk can be tested, and actions that turn out to predict crash involvement may be used as performance indicators in subsequent smaller studies and as the basis for development of countermeasures.

All ND studies that have been completed in the past were too small to enable such analyses. Therefore, estimates of relative risk have been based almost exclusively on data from near-crashes and not real crashes, and on untested assumptions regarding crash proxies. One possible exception is the ongoing SHRP2 study, which has been designed to be sufficiently large for the types of analyses mentioned here.

1.5.2 Cross-country comparisons

Although the SHRP2 naturalistic driving study is expected to yield very important knowledge that will be generally available, a parallel European study will enable interesting cross-cultural and cross-country comparisons. First, there are considerable differences between the road traffic systems in the U.S. and Europe, so that differences in crash-related driver behaviour may shed light on the effects of different road systems and legislations on crash risk. For example, the mix of pedestrians, bicyclists, and motorcyclists differs much between Europe and the U.S.. Furthermore, there are vast differences between the European countries regarding road infrastructure, road user behaviour and attitudes (traffic culture) and legislation, as well as crash risk. This gives the potential to yield very interesting insights as to how various factors may influence driver behaviour, and how driver behaviour and other factors impact on crash risk.

1.5.3 Environmentally friendly driving and traffic management

The ND approach has been used in the past primarily to investigate issues related to road safety, and it is clear that this is the research area where the largest contributions can be expected. However, the method seems well suited to additionally investigate some factors that determine the environmental effects of driving, and also driving behaviour with implications for traffic management. Both driving style and route choice are important determiners of emissions from vehicles. The latter is also relevant for traffic management purposes. An important distinguishing characteristic of the large-scale European study should therefore be investigations of environmentally friendly driving as well as traffic management. This could be done by adding recorders of minute-by-minute fuel consumption.

1.5.4 Vulnerable road users – new knowledge and new methods

The focus in most ND research has been on drivers. In the large-scale European study it is suggested to include also vulnerable road users (VRU). In the present context we define VRUs as pedestrians, bicyclists, powered two-wheelers, and other road users not protected by sitting inside a motorized vehicle. There are three different ways of studying VRU road users by ND methodology:

1. Analysing encounters between cars and vulnerable road users, identified by in-vehicle video recordings

2. Equipping bicyclists and motorized two-wheelers with simple recording equipment
3. Using site-based observations of traffic environments with a large share of vulnerable road users.

All three approaches will contribute to the unique characteristics of the European study and increase its added value. An example of using ND equipment for studying VRU is the EU project 2BeSafe, which involves ND observation of powered two-wheelers (*www.2besafe.eu*).

The site-based approach is a promising alternative naturalistic observation method for investigating vulnerable road user behaviour. In a typical ND study, the focus is on the behaviour and performance of the driver, and therefore the knowledge about VRUs is limited to occasional encounters between drivers and VRUs. This is primarily done in order to investigate the behaviour of the driver, and this information can be linked to the vehicle and the driving environment. Therefore the site-based approach is a useful supplement. A *site-based naturalistic study* was tested in the PROLOGUE project (Christoph et al., 2010). This trial resulted in several recommendations for how to utilise the combination of site-based and in-vehicle studies in future ND research.

In the past, site-based video recordings have been used for research on interaction between vulnerable road users and car drivers (Phillips et al., 2011), drivers' speed when approaching an intersection (Liu, 2007), and the duration of lane changes (Toledo and Zohar, 2007).

A particularly promising approach is to combine site based and in-vehicle studies; e.g. setting up a video-camera at a site where it is known that drivers in the in-vehicle study often drive. By use of continuous recording of vehicles' position by GPS, data from in-vehicle recordings can be synchronized with data from site-based recordings, and incidents may be analysed from various perspectives.

The use of combined data from site-based and in-vehicle recordings could possibly also be used to validate the in-vehicle naturalistic observations. By comparing site-based recordings of vehicles with and without in-vehicle recording equipments, based on matching by e.g. GPS, time, and video, it is possible to see if there are systematic differences in driving behaviour, and thus quantify potential effects due to sampling bias and the effect of study participation of the ND study drivers.

1.5.5 More advanced recording technology

The equipment for unobtrusive recording of driver behaviour has improved considerably during recent years, and this development is likely to continue. Therefore, future ND studies are expected to yield even better data than previous studies, due to equipment that will be more accurate, more reliable, less obtrusive, smaller, and cheaper. As mentioned before, eyetracker systems are especially likely to yield very useful information, and it is therefore important that the technological development is closely monitored during the preparation phase for a large project, in order that the most cost-effective equipment will be used.

1.5.6 Methodology for long-term monitoring

The large-scale study can contribute to developing a methodological platform for more longterm monitoring of safety performance indicators. The study is expected to yield knowledge about the most relevant indicators as well as on the most adequate equipment and procedures to be used for long-term monitoring of large samples of drivers (and riders). The DaCoTA project carried out in parallel with PROLOGUE has summarised the state of the art concerning monitoring of safety performance indicators, and thereby providing a background for piloting 'monitoring' in practice in a large-scale study (Talbot et al., 2011).

1.6 Reading guide

This report is roughly structured along the lines of Figure 1.2, the tentative modification of the FESTA "V" in an ND chain.

Part 1 of the report focuses on the interests of stakeholders (Chapter 3) and research topics (Chapter 2). This includes the identification of several stakeholders groups and the outcomes of a survey of stakeholder interests and several pan-European and regional workshops, regarding their specific interests in ND knowledge. In Chapter 2 the most prominent research topics are dealt with, starting with the distinction between research based on a priori research questions (things you want to know beforehand) and the added value a large ND database offers to answer research questions post hoc (afterwards). A distinction is made between driver-related categories (distraction, fatigue, speed, etc.) and conditions (driver background, road system, vehicle design, etc.). Each combination of category and condition delivers a set of research questions. The research topics are dealt with in more detail on road safety, eco-driving, traffic management, methodological issues (e.g. validation of other research methods, accident reconstruction etc.) and non-research applications of ND such as driver training.

Part 2 deals with the methodological aspects of a large-scale ND study. This includes a general overview of methodological requirements (Chapter 4), different designs for a study in which technology and sample size are varied (Chapter 5), indicators of driver performance and critical events (Chapter 6) and issues related to driver sampling and recruitment (Chapter 7).

Part 3 is on data issues. Specifications and requirements regarding the data acquisition system (DAS) and data collection and transfer procedures are part of Chapter 8. The analysis chapter (Chapter 9) deals with analysis methods, data reduction, access management and the various variables that need to be analysed.

The final Part 4 'Towards a large-scale naturalistic driving study' is an attempt to synthesize the needs (Part 1) and the available methods and technology (Parts 2 and 3). The European situation is essentially different from the U.S. There is no centralised research organisation or coordination (like TRB) to imply that specific research topics and stakeholder needs have to be met. An ND study is also not an FOT (Field Operational Test) in which measures are evaluated. The European large-scale ND study is likely to be a bit of both, combining a focus on specific topics that are linked to stakeholders' interests and building a general database suited for post hoc analysis. In part 4 we consider the relationship between technologies, samples and costs (Chapter 10), resulting in a few examples of possible studies and a framework that might be of help in designing alternatives (Chapter 11).

PART 1: Research topics and user needs

2 Research topics and applications

2.1 A priori vs. post hoc research questions

Although in principle any research study should be based on some *a priori* research questions or hypotheses, it should be recognized that a comprehensive collection of driver data with the most advanced recording technology under naturalistic conditions will also result in a database that can be used for investigating *post hoc* research questions. It is very likely that some research questions will appear later for which analysis of previous data can give a good answer. This is an argument for including as many variables as possible, as long as they can be recorded unobtrusively, and if they do not imply unreasonable additional costs, even if one does not have a theoretical rationale for each variable before the study. Such a database may be a very important source for subsequent studies of general aspects of driver behaviour.

In should be mentioned that building a large database is one of main purposes of the SHRP2 project, and it is expected to provide data to be used in post-hoc analyses for several years.

Although the ND database may be used for investigating post hoc research issues, it is of utmost importance that the study is designed to provide good answers to the known research questions for which the ND approach is considered to provide the most added value compared to more traditional research methods.

One should also be aware of the possibility that for some research topics the database may be obsolete in a short time, e.g. when it comes to assessing effects of various in-vehicle support or safety systems, since technological changes occur so rapidly that the systems in new vehicles may be very different from those in the large-scale study. This is an argument for biasing the sample towards newer vehicles. On the other hand, analyses of driver behaviour in relation to older systems may give useful knowledge about *general* aspects of driver interaction with in-vehicle technologies. The large-scale study will, however, in no way diminish the continuing need for naturalistic FOT studies in the future.

2.2 Overall research topics

Some of the "big" questions that could be answered by a large-scale ND study are:

- How do we get the "full" picture; i.e., how can we increase our understanding of driver behaviour and crash risk by integrating ND data with other data sources?
- How can we 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?

In the remainder of this chapter, the choice of research topics and questions is discussed in more detail, and a classification framework is developed.

2.3 The present approach to defining research topics and questions

The presentation of research topics will be based to a large extent on the SHRP2 work, with some additions and adaptations to European conditions, and on topics specifically identified in PROLOGUE. The SHRP2 work is very detailed with specific research questions (Boyle et al., 2009). In PROLOGUE more general research topics are formulated, and the detailed specifications are assumed to be left to the potential future project. For that purpose the SHRP2 catalogue of research questions will be a very useful source of reference, and it is useful also in the present stage to give an impression of some of the specific topics that can be addressed using the ND approach.

Thus, compared to the SHRP2 project the PROLOGUE project takes a somewhat different approach to defining global research questions. A categorization of research topics was developed in PROLOGUE WP1 (Sagberg and Backer-Grøndahl, 2010), and the following description is based on that work. The first step is a categorization of driving behaviours (and driver states inferred from behavioural observation) that are considered particularly relevant for investigation by the ND approach. This results in 8 driver-related categories. In addition we included a category for combinations of or interactions between behaviours, yielding a total of 9 driver-related categories.

Second, various conditions under which those behaviours and states can be observed (or inferred) are defined and categorized as well, together with background factors, into 4 specific categories plus 2 more general ones (combinations of conditions, and high-level topics), yielding a total of 6 categories for conditions.

Finally, the driver-related categories and the conditions/background categories are combined in a matrix with 54 cells (9 driver-related categories by 6 conditions). Those 54 combinations can be considered as *global research topics.* Each cell can then be filled in with specific research questions from different sources.

Road safety has been the primary focus of ND studies so far, and is clearly the topic where this approach has its main strength and added value as a research method. It is therefore recommended to utilise the distinguishing characteristics of ND research for further deepening and widening of the knowledge base needed for improving road safety and obtaining the ambitious goals of reducing the number of road traffic victims. In addition, naturalistic driving observation is well suited for studies of factors influencing the environmental effects of road traffic, including implications for traffic management. In the following presentation of research issues, the first part will be description of a general matrix for the classification of research topics based on the categories mentioned above. This will be followed by summary descriptions of the research areas, namely traffic safety (Section 2.4), eco-driving (Section 2.5), and traffic management (Section 2.6).

2.3.1 Driver-related categories

This section contains a description of categories of driving behaviour as well as driver states and conditions that can be inferred from behavioural observation. The driver-related categories are selected with a view to being conveniently investigated in ND studies. The relevant driver-related indicators comprise both driver and vehicle parameters.

2.3.1.1 Distraction and inattention

Distraction and inattention is a research area where the ND approach is especially well suited These phenomena represent some of the largest single causes of crashes, according to several studies, and to get more information about the circumstances under which drivers are distracted or inattentive, and how this contributes to crash risk, is of utmost importance. One important source of information about inattention and distraction in ND studies is observation of gaze direction. The quality of such data depends very heavily on the recording equipment (face or eye tracking cameras); it is notable that there has been a tremendous development of such equipment during recent years, both in terms of size, precision and price, so even better data can be expected in the future compared to the first and current ND studies. By combining outputs from cameras on the driver and on the traffic environment it is possible to get some information about which object(s) a driver is looking at. However, it should be noted that looking at an object does not necessarily imply attending to the object. The phenomenon of 'looked but did not see' can consequently not be inferred from gaze direction alone. Finding that a driver looks at some critical source of information but does not respond appropriately may be a relevant indicator of this phenomenon. When studying crashes, immediate post-crash interviews would be a useful approach for verifying cases of inattention.

When it comes to research on driver distraction factors in general, three different types of research issues can be identified: 1) potential *effects of* various distraction factors *on driving behaviour*, 2) *prevalence* of various distraction factors in *crashes*, and 3) estimates of *crash risk* associated with various distractions.

The potential of naturalistic driving studies within the field of driving distraction and inattention is multifaceted, and previous naturalistic driving studies have investigated all three issues described above. An advantage of the ND approach is the possibility to provide good and valid exposure measures in addition to incident and crash data, which is a necessary requirement for investigating the relevant research issues.

First, almost by definition, the ND approach addresses effects on driving behaviour of the distraction factors studied. The presence of the distraction in question is investigated in relation to various behavioural measures. The behaviour can be either the directly observed behaviour of the driver (e.g. eye glance pattern, number and position of hands on the steering wheel), or the observed result of being distracted, measured as position of the car, longitudinal and lateral accelerations, speed, following headway etc. The advantage of naturalistic studies compared to experiments is that the associations between distractions and behaviour are observed in a naturalistic and real context, and the study situation is not artificial.

Second, ND observation is also suitable for investigating the *prevalence of various distraction factors in crashes*. In particular, in studies with large samples conducted over a longer period of time, there will be a number of accidents, near-accidents, and critical incidents. However, as the number of accidents probably will be limited to some degree, near-accidents and critical incidents can be used as proxies for real accidents. Typically, in a naturalistic study, events (accidents, near-accidents, and critical incidents) are identified by means of quantitative, kinematic triggers that can be analysed in detail. A time slot of what happened before, during and after such events is subsequently analysed in detail, and the presence of distraction factors can be identified.

Third, in ND driving studies, estimating the prevalence of distraction factors in crashes is often just a part of a broader analysis of relative risks associated with various distraction factors. The main obstacle for estimating accident risk and relative risks in non-naturalistic studies is probably that it is difficult to get good exposure data on distraction factors. That is, one does not have information about how often drivers are exposed to or engage in various distractions in their normal driving, i.e., not related to accidents. In ND studies, however, one has the potential to record driving behaviour continuously, and thus estimate relative risks.

By using ND data on prevalence of distractions in general as well as during accidents and near-accidents, relative risks (odds ratios) and corresponding *population attributable risk* (PAR - to be explained and discussed in Section 2.4.2) can easily be estimated, provided one has adequate procedures for identifying and coding the distraction episodes, either by triggers or by video inspection.

Secondary task engagement

It is not only the *effect* of driver distraction (i.e., distraction as the independent variable) that may be of interest, but also driver distraction as outcome or the dependent variable.

Drivers very often engage in various tasks that are not directly related to the primary task of driving. Some of those may be related to the driving situation, such as e.g. adjusting the air-conditioning or defroster system, whereas others are unrelated to the driving (e.g. changing CDs, talking on a mobile phone). The distinction between driving related and unrelated tasks is far from clear-cut. For example, interacting with a navigation system may be related to driving at a strategic level, whereas it may not be relevant to the actual driving situation here and now (i.e. for driving tasks on the tactical or operational level).

The increase of in-car communication, information and entertainment systems, which has taken place particularly during the last decade, may have increased the number of possible sources of driver distraction.

An interesting question with regard to the effect of in-vehicle support or warning systems is whether such systems have any unintended effects on behaviour. One possible mechanism that may indirectly result in distraction is risk compensation. That is, the perceived (and intended) increase of safety that comes with an in-vehicle safety system is compensated for by more risky driving behaviour, for instance driving faster or more aggressively, or engaging in more secondary (distractive) behaviours. In other words, support systems may result in distraction in two different ways, first by drivers attending to information from a system, and second, by allowing drivers to engage in non-driving related secondary tasks because of relying too much on a warning system.

Thus, naturalistic driving studies allow for investigating driver behaviour associated with various in-vehicle systems, like for instance risk compensation and behavioural adaptation, as well as testing and evaluating various systems. For this purpose, long-duration studies – longer than typical FOTs - may be necessary, in order to assess the long-term behavioural adaptation effects of the systems.

Perception and processing of driver information

The phenomena of distraction and inattention are closely related to drivers' perception and processing of information from the driving environment, including both inside and outside the vehicle. Driver perception and information processing cannot be observed directly, not even with the ND approach. However, some inferences can be made from observation of visual search behaviour in relation to information provided by signs and markings, combined with observations of the driver reactions to the information, e.g. in terms of complying with regulatory information, changing lanes to prepare for exits, etc. Audio recordings would be a useful additional source of information, as well as subsequent interviews with drivers.

2.3.1.2 Fatigue, sleepiness and other acute impairments

A second large crash cause is fatigue and sleepiness (or *hypovigilance*, to use a somewhat wider term covering many different states of reduced alertness). This is somewhat related to the topic of inattention, since fatigue or sleepiness may be one out of several possible causes of inattention.

Impairments related to other conditions may also be observed. Although the cause of impairments rarely can be observed (e.g. illness, medication, alcohol, or drug use), the data may give some indications about impaired driving, regarding its prevalence under various driving conditions. It would also be interesting to determine to what extent various driver and vehicle based measures (e.g. eye movements or steering-wheel reversal rate) can distinguish between different types of impairments.

In order to understand driver drowsiness and its effects on driving behaviour and accident risk, there are various issues that need to be addressed in research, e.g. how to measure drowsiness, occurrence of driver drowsiness, the causes of drowsiness, how to model drowsiness and accident risk, as well as developing countermeasures for driver drowsiness and accidents. In particular, we need to be able to identify driver drowsiness so that (a) reliable countermeasures can be developed (based on objective measures of driver drowsiness rather than less reliable subjective measures of driver states); and (b) it can be more easily classified as a variable in epidemiological and other research studies. ND studies have the potential for gaining more reliable and valid measures of driving drowsiness, by measuring e.g. lane deviations and eye-closure. Moreover, ND studies of driver drowsiness can give more valid information on the circumstances and times of day when driver drowsiness is most frequent.

Driver drowsiness is especially interesting with regard to commercial drivers and in particular long haul drivers as they drive for long durations and at night. One possible application of such knowledge may be implementation of fatigue management programmes in commercial vehicle companies, and also in other occupational settings (see e.g. Phillips and Sagberg, 2010).

2.3.1.3 Decision-making, driving errors, driving style and general driving performance

This is a rather wide category of driver behaviour, covering decision-making and actions during driving more generally, in relation both to the car (car handling) and to the traffic environment. This is supposed to cover behaviours not included in the more specific categories that are described in this document. Examples of car-handling actions include use of controls like turn signals, headlights, gear, etc. Actions related to the traffic environment include e.g. overtaking, route choice, etc.

It should be noted that this issue is closely related to that of information processing mentioned in the section on distraction and inattention; e.g. one possible source of decision or action errors may be misunderstanding or failure to observe some important information.

Much has been written about driving errors and crash risk. This is a very wide category, which has to be specified to some extent in order to be a meaningful concept. A useful conceptualisation of errors is the one by Reason (1990) in terms of slips, lapses and mistakes.[2]

The error categories according to Reason have been operationalised in the Driver Behaviour Questionnaire DBQ (Reason et al., 1990; Parker et al. 1995), which has appeared in different versions. Although it has yielded many interesting results, it suffers from the limitations of any self-report instrument regarding its validity as an indicator of actual behaviour. ND will make it possible to get observational data about the various types of errors included in the DBQ, e.g. car-handling errors, which may be a relevant risk factor particularly among inexperienced drivers (see e.g. Bjørnskau & Sagberg, 2005).

[2] The classification by Reason includes violations as well. However, we believe that ND is not particularly well suited for studying violations in traffic, at least not intentional violations, because of the driver's knowledge that the driving is being recorded. There may, however, be unintentional violations, but such behaviours are subsumed by the other error categories. The topic of violations will therefore not be included in the list of research topics in the present document. If, however, further methodological studies of the ND approach confirms that drivers adapt completely to being monitored, the assumption that ND participants are unlikely to commit deliberate violations may have to be qualified in the future.

Driving style and performance is also one aspect that is interesting to include in ND studies, not only in relation to safety, but also regarding environmentally friendly driving style as shown by acceleration/retardation profiles, gear shifting, etc. Although we have included speed and acceleration as a separate behavioural category (see Section 2.3.1.5 below), it is considered convenient to have a more general category covering several aspects of driving style.

Seating posture

Knowledge about typical seating positions of drivers may be useful for the development of occupant protection systems such as airbags and seatbelts. Frequency of seatbelt use as well as possible erroneous use can also be recorded. A related issue is the prevalence and typical patterns of "out-of-position occupant" (OOPO) events, which may have importance both for probability and consequences of a crash.

2.3.1.4 Lane change and lane position

Several parameters of lane position are potentially relevant. Variations in lateral position (e.g. expressed as SDLP[3]) may be relevant to assess inattention and other driver impairments. Frequency of lane changes is another variable of interest. Lane preferences on roads with two lanes or more may also be studied. Apart from the possible implications of lane-keeping and lane-change behaviour for safety, lane choice may also influence traffic flow. An interesting issue is e.g. to what extent drivers are able to choose the lane that is optimal from the point of view of minimising travel time.

2.3.1.5 Speed and acceleration

Driving speed is a very important variable for which ND can give useful knowledge beyond what is known today. Especially important is the possibility to get information about speed adaptation to variations in the driving environment, e.g. road geometry, pavement quality, weather and light conditions. Most studies of natural driving speed so far have yielded knowledge about either average speeds or the speed at specific measurement points, whereas speed profiles have been less thoroughly investigated. In relation to risk, it will be of interest to know how various groups of drivers adapt their speeds (and safety margins) to e.g. curves and intersections, and to varying traffic conditions.

2.3.1.6 Gap acceptance

Thresholds for gap acceptance may vary both between drivers and across situations for each individual driver. Furthermore, erroneous judgment of minimum safe gaps is probably an important risk factor. There are many different aspects of gap acceptance that are relevant in ND studies, e.g. time headway to a lead car, time gaps between crossing vehicles when waiting at a yield or stop sign, or gap to an oncoming car when considering to overtake.

2.3.1.7 Aggressive driving

So-called "aggressive driving" has been the subject of much recent research. Although it is a somewhat ill-defined concept (see e.g. Shinar, 1998, for a discussion of the concept), there are at least some behaviours that are generally agreed to be examples of aggressive driving, such as extreme speeding, tailgating (especially when combined

[3] SDLP = Standard Deviation of Lateral Position

with honking or flashing of headlights), deliberately violating priority rules, showing one's anger by making gestures to other road users, or any other behaviour for intentionally provoking fear or causing problems for other road users. The term "road rage" has been used to characterise parts of aggressive driving. Although the most extreme forms of aggressive driving behaviour may perhaps be attenuated in ND studies because of the driver's awareness of being observed (cfr. the discussion on errors and violations above), there are many behaviours akin to aggressive driving that are likely to occur even in the ND situation, and which may give important knowledge about their prevalence as well as their implications for crash risk.

It should be acknowledged that "aggressive driving" is an inference based on observation of different behaviours, such as speeding, time gaps, etc., and thus there is an overlap with some of the other categories of directly observable behaviour mentioned in this section. Despite this overlap, we consider it useful to include "aggressive driving" as a separate category, due to its potentially strong negative impact on road safety.

2.3.1.8 Learning

The importance of driving experience for safe driving has been clearly demonstrated in previous research (e.g. Mayhew, 2003; Sagberg & Gregersen, 2005), and ND is well suited to give more knowledge about this learning process, by observing drivers with different amount of driving experience. It has been shown that novice and experienced drivers differ in many aspects of driving behaviour that may be relevant to safety, such as hazard perception (e.g. McKenna & Crick, 1997; Sagberg & Bjørnskau, 2006) and visual search behaviour (Rockwell, 1972).

In a more applied perspective, the ND methodology is used to some extent as part of driver training, with the purpose of providing feedback to the learner driver after the lesson. The potential of such applications for increasing the effectiveness of driver training is a promising area for further studies.

It should be noted that learning cannot be directly observed, but has to be inferred from observing changes in behaviour.

2.3.2 Situational categories (conditions)

The various behaviours, which were categorised in the previous chapter, may occur under many different conditions and in different driving situations, as indicated by some of the mentioned examples of research issues. There is therefore a need of a categorisation of conditions as well, to obtain a complete framework for formulating future research topics and questions.

2.3.2.1 Driver background factors and trip characteristics

The ND approach is valuable with regard to investigating behaviour of *different types or groups of drivers*. For example, epidemiological research consistently shows that young and elderly drivers are at increased accident risk, drivers suffering from various chronic diseases have been found to have increased accident risk, driving under the influence of alcohol or other substances are associated with increased risk. Naturalistic driving studies are suitable for investigating driver behaviour and accident risk associated with some of the driver characteristics and states, such as for instance young and elderly drivers and drivers with various health conditions, whereas the method may be less suitable for investigating, for instance driving under the influence of alcohol or other substances. In particular, even though it is assumed that the unobtrusive nature of naturalistic observation is quite resistant to observer effects, one has to expect that drivers will refrain from extreme behaviours (like driving under the influence of alcohol) when participating in a naturalistic study.

The driver conditions discussed in this section are to be distinguished from the driver states that were included among driver-related categories listed in Section 2.3.1. The driver-related categories listed there included relatively acute or temporary states, whereas the driver background categories included here comprise relatively permanent conditions, which may predispose drivers by facilitating or inhibiting certain driving behaviours or acute states.

Motives for driving (including emotional motives) may be one relevant characteristic in this category, for example whether driving is undertaken just for getting safely from A to B, for enjoying speed and excitement, for enjoying driving pleasure, or for showing off to passengers or other road users. There are differences between drivers concerning their most typical motives for driving, and the motives may also differ between and during trips for each driver.

Some relevant driver characteristics may be recorded by means of various tests of personality traits, attitudes etc., e.g. Sensation Seeking Scale, Driver Behaviour Questionnaire, cognitive style, masculinity-femininity.

Young drivers

Concerning the young driver issue, one could for instance investigate behaviours at the operational level that are assumed to be more frequent among young drivers than more experienced drivers, as well as more tactical behaviours such as engaging in secondary or tertiary tasks while driving. Moreover, with larger samples of young drivers one could get data on accidents and near-accidents allowing for both statistical analyses of accident risk as well as more in-depth analyses of behaviour preceding accidents. Finally, an interesting issue would be to investigate behaviour and incidents as a function of driving exposure.

Health problems and driver impairment

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

Driving with passengers

Having passengers in the car has been shown to affect crash rate in rather complex ways. Among other things, the effect seems to depend on both driver and passenger age as well as on the number of passengers. Data on the actual interaction between driver and passengers in cars, provided by ND research will hopefully result in a better understanding of these complex relationships, and also the possible role of other factors. It should be noted that the presence of passenger raises some legal-ethical issues as the passengers do not volunteer for the study. This is further discussed in Section 7.5.

2.3.2.2 Road system, road environment, ambient conditions

Driver behaviour is obviously dependent on the road environment and other ambient conditions. One of the advantages of the ND approach is that information about these factors can be recorded together with the behaviour indicators, in order to study how the various road and environmental factors modify driving behaviour. A general overview of some relevant aspects is given here. For a more detailed specification of both road and environmental parameters in ND studies we refer to PROLOGUE Deliverable D2.2. (Groenewoud et al., 2010). Some road system parameters can be recorded directly as part of the ND observation, some can be added subsequently by using time and/or location (GPS coordinates) for matching the primary data to other databases (e.g. GIS-based road network data), and some can be recorded in both ways. Matching driving events to GIS-based road network data was trialled in PROLOGUE (Lotan et al., 2010; see also Section 9.5)

Road system parameters are highly relevant for investigating research questions as well as for monitoring of the "driving context" (cfr. DaCoTA WP Deliverable 6.1; Talbot et al., 2011)

Comparison of behaviour across different driving environments may yield knowledge about risk factors related e.g. to road design parameters. For example, if crash statistics show that certain types of intersections have a higher crash risk than other types, it may be useful to find out whether drivers behave differently in these environments. Such knowledge may result in suggestions for countermeasures to correct the problem and also to improve guidelines for design. Assuming that vehicle position is continuously recorded in an ND study it is possible to select driving episodes for specific environments for detailed behaviour observation, e.g. "blackspot" locations.

Similarly, it is possible to study parameters like lane or road width, number of lanes, etc. For example, previous research has shown that speed increases when the road widens, but less is known about effects on driver concentration. For example, are drivers focusing less on the road when it becomes wider? And is there an interaction between speed change and concentration of attention to traffic as a function of variations in road geometry?

Although road category is to some extent correlated with road geometry, comparing driver behaviour between different road categories may be interesting in itself.

The traffic system is designed on the assumption that drivers attend to information provided by signs and markings, that they know the meaning of that information, and that they comply with regulations. Lack of compliance may result from either inattention to the information, a lack of understanding, or deliberate violations. ND studies may contribute primarily to knowledge about attending to the information, and to how drivers react to the information.

Weather and light conditions are important factors to influence behaviour. There are both effects of visibility changes and changes in road friction that can be studied.

Differences across countries

Several aspects of the road and traffic systems, as well as the legislation related to those systems, vary across countries. A large European ND study will therefore enable comparisons of driving behaviour between different road and traffic systems, and comparison of ND data between countries may give useful information about advantages and disadvantages of different traffic system designs, forming the basis of future best practice recommendations.

For this purpose it is very important that the research method is fairly standardized across the geographical areas where the study is conducted.

2.3.2.3 Vehicle design, equipment and condition

Although much is known about various vehicle characteristics and crash risk, there is a lack of knowledge about the behavioural mechanisms involved in the interaction with the vehicle. The ND approach is very well suited for filling this knowledge gap. Many aspects of car design may possibly influence safety-related aspects of driver behaviour. For example, the design of the vehicle compartment may influence visibility to outside objects. Design of controls and displays may influence the risk of vehicle-handling errors and likelihood of various control movements. The impact of new ADAS and IVIS systems is also an interesting topic for ND studies. Although such systems are tested in FOTs as part of the product development, ND studies that oversample new model cars may give useful additional knowledge as a basis of future improvement of most kinds of vehicle equipment.

Concerning visibility, forward and lateral video will enable identification of incidents where the view to external road users or other objects has been obstructed by some part of the vehicle. A design feature acknowledged as a possible sight obstruction is the increased size of the A-pillars in modern cars compared to older models. ND research is well suited for investigating to what extent this is really a problem.

Vehicle design in relation to distraction and inattention is an interesting topic. A hypothesis could be that a highly automated vehicle with many support and warning systems influences driver objective and subjective workload to the extent that less effort is directed to the driving task, and the probability of engaging in secondary tasks (see Section 2.3.1.1) may increase. This would be an example of “risk compensation”, possibly resulting in sub-optimal effects of safety systems.

A related question pertains to fatigue. Vehicle design (noise and vibration level, general driving comfort, presence of airconditioning, support systems, etc.) may have an effect on the experience of monotony and boredom while driving, and the question whether this also affects the likelihood of falling asleep while driving can be investigated in ND studies.

Weight/power ratio and acceleration performance is also an interesting variable. The relationship of vehicle performance and driving style, e.g. gap acceptance when overtaking, is interesting, although it is a methodological challenge to separate effects of the vehicle from driver-related factors.

2.3.2.4 Traffic volume and composition - interaction with other road users

Traffic volume

Drivers are likely to behave differently in dense as compared to less dense traffic; e.g. in terms of speed and headways. Attempts to investigate crash risk as a function of traffic density have generally shown rather weak (and complex) relationships, although theoretically one should expect risk for some crash types to increase monotonically with the frequency of encounters with other vehicles. Observing actual behaviour may shed more light on how drivers adapt to changing amounts of traffic.

Vulnerable road users

Although ND studies have their primary focus on driver (or rider) behaviour, the data can indirectly give information about behaviour of vulnerable road users as well, such as pedestrians and bicyclists. From an ND database it is possible to select encounters between the equipped cars and any other type of road user, in order to study risk factors associated with the interaction between different road users.

An additional source of knowledge about interaction between cars and vulnerable road users is site-based observation, which has been evaluated in the PROLOGUE project (Christoph et al., 2010), by observing behaviour in an intersection (cfr. also Section 1.4.4).

Powered two-wheelers (PTW) make up an important group concerning crash risk among vulnerable road users. PTW use has increased in many countries, and their share of fatalities seems to be increasing as well. A very frequent cause of collisions between cars and PTWs seem to be the so-called “looked-but-failed-to-see“ error, which still needs better explanations, that can hopefully be provided by ND studies.

Heavy vehicles

A very high share of road fatalities is caused by crashes between heavy vehicles and cars. For example, Norwegian crash statistics show that about 30% of all road fatalities occur in crashes involving a heavy vehicle. Understanding car driver behaviour in encounters with heavy vehicles is therefore of high importance, and may possibly give some indications regarding possible countermeasures.

2.3.3 The “behaviour x condition” matrix

The global research topics in this document are formulated in terms of *behavioural indicators*, whereas the ultimate effect variables of interest are safety, mobility or sustainability. However, for most behavioural indicators, ND studies are supposed to provide knowledge about their frequency during driving in general (exposure) as well as during incidents, near-crashes and crashes. Because drivers adjust their behaviour to the environmental conditions, it is critical to study these behaviours in their interaction with the environmental conditions.

There is also previous empirical and/or theoretical research indicating their relevance to crash risk. Thus, research topics regarding crash risk can be derived from the formulations here regarding driver behaviour.

Table 2.1 is a matrix where all combinations of the driver-related categories and the various driving conditions listed above are included (9 driver-related categories X 6 conditions = 54 cells). For each combination of a driver-related category and a driving condition, more specific research topics or questions can be listed.

The cells of the matrix in Table 2.1 can be considered as categories of research topics, and they are assumed to cover the main topics that are considered particularly suited for ND studies.

One example of a more specific research question could be “Is falling asleep while driving more likely on monotonous roads?”, which belongs to the cell formed by the driver-related category “Fatigue, sleepiness, other impairments” and the driving condition category “Road system, road environment, ambient conditions”. A second example is “Do drivers travel at lower speeds when pedestrians (especially children) or bicyclists are present?”, which belongs to the cell formed by the categories “Speed and acceleration” and “Interaction with other road users; traffic volume”.

For additional examples of how the cells of the matrix can be filled in with specific research topics and questions we refer to PROLOGUE Deliverable D1.3 (Sagberg and Backer-Grøndahl, 2010).

Table 2.1; Matrix of research topics, based on combinations of driver-related categories and driving conditions

<table>
<tr><th rowspan="2">Driver-related categories</th><th colspan="6">Driving conditions</th></tr>
<tr><th>General research topic or question</th><th>Driver back-ground factors and trip char-acteristics</th><th>Road sys-tem, road environ-ment, ambient conditions</th><th>Vehicle de-sign, equip-ment and condition</th><th>Interaction with other road users; traffic volume</th><th>Combina-tion of two or more conditions</th></tr>
<tr><td>Distraction and inattention</td><td colspan="6" rowspan="9">Specific research topics and questions</td></tr>
<tr><td>Fatigue, sleepi-ness, other im-pairments</td></tr>
<tr><td>Decision-making, errors, driving style/ perform-ance</td></tr>
<tr><td>Lane change, lane position, lane keeping</td></tr>
<tr><td>Speed and accel-eration</td></tr>
<tr><td>Gap acceptance and headway</td></tr>
<tr><td>Aggressive driv-ing, compliance with regulations</td></tr>
<tr><td>Learning</td></tr>
<tr><td>Multiple behav-iours/ states, interactions</td></tr>
</table>

2.4 Traffic safety

2.4.1 Exposure and risk – developing crash surrogate measures

For many of the risk factors that are identified by investigating various research topics by ND studies, an important purpose is to quantify the crash risk associated with the various factors and to identify relevant behavioural indicators that can be used as crash surrogate measures. For this purpose there are two basic types of data that are provided very effectively by the ND approach. First, the method is very convenient for providing data on *exposure* (or *prevalence*) of the various risk-related behaviours that are observed. This is knowledge that is very much needed in road safety research, and which is difficult to collect by more traditional research methods. A large part of the available research on risk factors in traffic suffers from limited exposure data. When available, exposure data are only on aggregated levels, making it very difficult to estimate crash risk for subgroups of road users or variations of risk in time and space; e.g. daytime, different driving environments, etc. Often one has to rely on self-report, with its known limitations in terms of low response rates as well as bias in reporting. With the

ND approach it is possible to take random samples of driving and record the proportion of the time where a given behaviour occurs, e.g. telephoning, talking with passengers, speeding, or any other behaviour that can be observed.

The second type of data is *risk estimates*. Large-scale ND studies, involving several millions of vehicle kilometres, necessarily will include a substantial number of crashes (primarily PDO crashes, since injury crashes are rare), and several near-miss incidents. (See Section 7.2 for estimates of expected number of crashes in relation to the size of driver/vehicle samples.) By counting the occurrences of potential risk related behaviours at the time of the crash or incident, and comparing the frequencies with the prevalence during baseline driving, *relative risk* can be estimated with far better accuracy than with alternative methods. ND makes it even possible to estimate risk for certain factors for which no previous estimates are available. The risk-related behaviours identified from ND data can in the next turn be used as crash surrogate measures in smaller ND and FOT studies. *Thus, the development of crash surrogate measures based on risk estimates should be considered one of the main purposes of a large-scale ND study.* This is in accordance with conclusions from the joint FOT-net/PROLOGUE/DaCoTA near crashes workshop, 30 November 2010 (*http://www.fot-net.eu/en/news__events/events/past_fot_events/near_crashes_fot-net_prologue_and_dacota_workshop.htm*). In general, participants at the workshop recommended conducting *large-scale monitoring* with high level instrumentation; near-crash detection may not be feasible with simple devices. It was also pointed out that video is a must for validation of crash-related events and scenarios, identifying driver state and gaze direction, and discard false alarms.

Experiences from PROLOUE field trials and other studies confirm that recordings of *g* forces alone is not sufficient for reliable identification of incidents and near-crashes, e.g. close encounters where the ND driver fails to react at all, and a crash is avoided by actions of another road user. False alarms were also a problem in the field studies. These experiences show clearly the importance of additional video recording.

Risk estimates can be obtained not only for driver behaviours, but also for various environmental conditions, such as billboards, fog, and view obstructions.

Exposure data derived from ND studies, in addition to being used for relative risk estimates in the same studies, can be used also for estimates based on other crash databases.

2.4.2 Individual risk and population attributable risk

Whereas the concept of *crash risk* is usually used to indicate *individual risk* in terms of crashes per unit of exposure, a different concept capturing the *societal impact* of a risk factor is *population attributable risk* (PAR). Briefly explained, PAR is an estimate of how much the *excessive risk* associated with a certain factor contributes to the aggregated number of crashes in a jurisdiction. In other words, it estimates the hypothetical reduction in the number of crashes that would be obtained had the relative risk of a certain factor been reduced to 1. The PAR is a function of both the relative risk and the prevalence (exposure) of the factor in question. For example, a risk factor with a very high crash risk may have a low PAR if its prevalence is very low, and consequently the societal impact may be low. This may be the case e.g. for some rare health conditions. One example is narcolepsy, which is probably associated with a high crash risk, but has a low prevalence. On the other hand, a risk factor associated with a low relative crash risk may have a high PAR if it is frequent. An example of such a condition is impaired visual acuity, which is associated with only a slightly elevated crash risk but has a high prevalence in the population (when we include minor refraction errors). The PAR is important for assessment of the possible effects of countermeasures in terms of reduction in the number of crashes.

ND studies are particularly well suited for estimating PAR because they enable estimates of both prevalence and relative crash risk.

Even a large-scale ND study cannot be expected to include a large number of serious crashes, not to mention fatalities, due to the fortunately rare occurrence of such events. Therefore, exact risk estimates can be provided for PDO and slight injury crashes only. Since it cannot be assumed that fatal crashes are equivalent to less serious crashes in terms of the accident causation mechanisms, the development of crash surrogate measures for fatal crashes has to be based on combining the ND data with data from other sources, e.g. in-depth studies of fatal crashes, or on theoretical models of the relationship between crashes of different severities. A review and development of appropriate models for this purpose should be part of the large-scale European study.

2.5 Eco-driving

A possible topic which can be investigated by the ND approach is energy-saving driving behaviour, and the various conditions influencing such behaviour. “Eco-driving” or “green driving” denotes a smart and smooth driving style that is assumed to reduce fuel consumption and greenhouse emissions. More specifically, eco-driving is characterised by (a) shifting to a higher gear as soon as possible, (b) reducing speed variability, (c) keeping high gear and low rpm (d) anticipating traffic flow, and (e) decelerating smoothly (*www.ecodrive.org*). Driving speed, acceleration and deceleration profiles, braking, and gearshift behaviour, are among the most relevant indicators. Energy consumption by motorised vehicles is a concern of increasing importance for authorities, and it is therefore useful to have knowledge about the potential effects of countermeasures to change driving styles towards more fuel economic driving.

Eco-driving has been on the agenda for some years, with training courses and evaluations, especially for professional drivers. The PROLOGUE literature survey (Backer-Grøndahl et al., 2010) identified a couple of studies that showed some effects of eco-driving courses on fuel consumption. Although some relevant aspects of driving behaviour were measured in those studies, there is a need for more comprehensive ND studies in order to understand the factors that may contribute to environmentally friendly driving.

Another aspect that should be mentioned in the context of eco driving at the strategic level is 'trip planning', e.g. combining trips, using less congested hours, etc.

A detailed discussion of the environmental relevance of naturalistic driving can be found in a paper by Richard Smokers, TNO, which is included in Appendix I. An excerpt of his paper is included here:

> “This paper illustrates the influence of driving behaviour on real-world vehicle emissions and fuel consumption, and motivates why and how experiments with ND are relevant for increasing our knowledge on ways to reduce the environmental impact of traffic by means of influencing driving behaviour. In the short term this knowledge can be used to design effective measures for improving air quality in urban areas. In the longer term more detailed knowledge of the relation between driver behaviour and vehicle energy efficiency is relevant for the optimal design of efficient vehicles and in-car driver feedback instruments as well as of advanced traffic management systems and other ITS applications that will help to reduce CO_2 emissions from transport in a cost effective manner.”
>
> “Fuel consumption and emissions of road vehicles are determined by three major factors:

- Technical aspects of the vehicle
  - engine technology and exhaust aftertreatment
  - vehicle mass, rolling resistance and aerodynamics
- Traffic circumstances
  - road type
  - maximum speed
  - level of congestion

- Driver behaviour
  - driving style
  - use of (energy consuming) accessories

These three factors can also be used to limit fuel consumption and emissions. In the case of technology this is done mainly through emission legislation (e.g. Euro standards and CO_2 legislation). Traffic circumstances are influenced by road design, and on existing roads they can be changed by means of traffic management measures. Driving behaviour is e.g. influenced by campaigns or lessons promoting the application of an energy efficient driving style. Behavioural changes can be supported or further enhanced by using in-car fuel consumption feedback instruments."

"Including environmental aspects in large-scale experiments with ND may require changes in the set-up of the experiments. These changes may include additional recording of parameters related to driver behaviour or vehicle driving characteristics in a given experimental set-up or even changes in the situations to which drivers are exposed during the experiment.

Requirements with respect to vehicle driving characteristics include the recording of speed / time / location information and if possible also instantaneous fuel consumption (e.g. from the vehicle CAN-bus). Actual vehicle emissions are difficult to measure in real-time. Emission measurement, however, is not necessary as the impact of changes in driving style on emissions can be estimated using advanced off-line emission factor modelling.

It is expected that speed / time / location information will already be recorded for other purposes in most experiments with ND. Collection and statistical analysis of this information will already contribute considerably to the knowledge base that is necessary for assessing the influence of driving styles on environmental performance and for the correct design of advanced traffic management measures.

Changes in the recording of driver behaviour may relate to the response of drivers to information provided from the road side or by in-car instruments. Such measurements will generate insights that are crucial for the optimal design of measures such as in-car instruments, advanced traffic management and ITS that are intended to influence driving behaviour for the improvement of traffic flow and/or environmental impacts of traffic."

2.6 Traffic management

A question related to environmentally friendly driving, is that of effective traffic management and minimization of travel time, since reduced travel time generally means lower energy consumption and less emissions.

Although there are some studies of lane changes and lane preferences that may be relevant to traffic management and flow (see Backer-Grøndahl, 2010 for a review), those studies are scarce, and there is clearly a need of more research in this field, focusing also for example on drivers' route choice in relation to travel time.

Conceivably, naturalistic driving data may be applied to micro simulation for traffic management and strategic road network planning.

Typically data for micro simulations are gathered by observing the flow of traffic at discrete locations in the road network. These observations may count the number of vehicles passing through the location using a single fixed camera or record the speed of the vehicle through a short stretch of road by using two fixed cameras. This method provides information relating to large numbers of vehicles but only provides snapshots of the network. Whilst these are useful data, it has been noted by stakeholders (see e.g. minutes from PROLOGUE regional workshops; Eichhorn & Van Schagen, 2011) that there are drawbacks to this approach and that on occasions the results of simulations using snapshot data can provide misleading results. Stakeholders are keen to include additional data in simulations that provide information about continuous travel on roads of interest. They are also keen for knowledge relating to driver behavioural characteristics in particular scenarios (e.g. through roadworks, at roundabouts, at known accident black spots) in order to enhance the variables included in traffic simulation models. A large-scale ND study provides the opportunity to contribute valuable data to this field.

Another application of data, in a large enough study, would be to identify potential accident black spots where infrastructure interventions could be used to mitigate the accident potential. Black spots are identified after the event at present; that is to say that once a number of accidents have occurred, the location is considered ‘high risk’ and typically warnings are given or mitigation measures taken. By monitoring driving behaviour through naturalistic observations and identifying ‘hot spots’ of specific indicators such as a need for harsh braking or lane departure (for example), a picture of potential future black spots can be formed and appropriate action taken in advance of accidents occurring.

2.7 Methodological research on naturalistic driving

2.7.1 Validation of alternative methods

In addition to the research topics summarised above, there are some more global aspects of research methodology that can be studied by using the ND approach. It should be pointed out that ND is not to be considered only as an *alternative* to other and more traditional methods, but also as a *supplement*. One possible use of ND methodology can be for validation of other approaches. For example, by comparing ND observation with self-reported behaviour it is possible to get information about the validity of self-reports and about factors that may produce systematic biases in self-reports.

2.7.2 Accident reconstruction

Concerning accident investigations, the ND approach may be used to validate other methods for accident reconstruction. This can be obtained by subjecting crashes in ND-equipped cars to traditional accident investigations and reconstruction (by analysts who are blind to the ND data), and then using the ND data as a criterion of validity afterwards.

Another related issue is the validation of witness statements after accidents, where information from the ND observations can be an important validation criterion.

2.7.3 Combining in-vehicle and site-based observation

There may also be methodological issues related to the ND approach itself, which should be studied in more detail. Although the ND approach has several obvious advantages as a research method for understanding driver behaviour, and enables studies of behaviour that cannot be studied with any reasonable validity by other methods, there are some possible limitations. Although e.g. the reports from the 100-car study indicate that drivers behave normally despite their behaviour being recorded, the possibility of observer effects on behaviour cannot be ruled out entirely (see Backer-Grøndahl et al, 2010, for a discussion of observer effects in ND studies). A relevant issue for future research is therefore the validity of ND data regarding different aspects of behaviour. A possible hypothesis is that the more deviant or illegal the behaviour, the less valid the ND observations.

One possible approach to validation of some behaviours could be the use of a combination of in-car ND observation with site-based observation in places where a large number of ND-equipped vehicles are expected to travel (cfr. Section 1.4.4). Assuming a system for identifying ND-equipped vehicles, the on-site observation could involve comparison between vehicles with and without ND equipment regarding certain behaviours, like e.g. speed, priority sign or traffic light violations, etc. Differences between the two groups of vehicles might indicate possible observer effects.

Procedures for automatic identification of vehicles with ND equipment would be an important improvement of the site-based observation approach. Further methodological improvement of site-based observations may involve use of a multicamera approach for a more complete coverage of traffic situations.

The combination of in-vehicle and site-based observations may further be used for mutual validation of speed profiles derived from the two different methods, e.g. for vehicles approaching intersections.

2.7.4 Surrogate measures of crashes

The ultimate goal of ND research as far as road safety is concerned is to study crash-relevant behaviour. Since crashes are infrequent whereas incidents and near-crashes are rather common, it is imperative to get as much knowledge as possible from the latter events. However, behaviour in an incident or near-crash is not necessarily representative of behaviour resulting in a crash. Therefore, one of the benefits of a large-scale study is that it necessarily will include some crashes as well, and thereby enabling comparison of behaviour in crashes with behaviour in near-crashes and incidents. This will contribute to more knowledge about the most relevant surrogate measures for crashes to be used in other studies.

2.8 Non-research applications

2.8.1 Basic driver training

Conceivably the technology for behaviour observation that is used in ND research may be used in practical applications as well. One example is driver training, where some traffic schools install cameras in their cars for recording the behaviour of the driving students during lessons. The purpose of this is to use the recorded data for reviewing the lesson as part of the teaching. In PROLOGUE, the use of feedback from ND observations of learner drivers was assessed in the Austrian field trial, and some indications of a favourable effect on post-licence risk-related events was found (Gatscha, Brandstätter & Pripfl, 2010)

Feedback based on ND observation systems has been used also in the graduated licensing phase for novice drivers driving on their own. This was done in an Israeli study (Prato et al., 2010), yielding the interesting finding that driving behaviour feedback monitored by parents was related to less risk-related behaviour among the novice drivers. This work was part of the basis of the research in the Israeli field trial in PROLOGUE (Lotan et al., 2010)

Another application has been eco-driving (see Section 2.5), where feedback on fuel consumption and driving parameters has been used for the purpose of training drivers to drive more fuel-efficiently.

The ND approach could in principle be used in any type of lessons for drivers, where the purpose is to influence driving behaviour. One potential application could be courses for elderly drivers.

2.8.2 Monitoring of safety performance

Monitoring of safety performance indicators for statistical purposes is a very useful application of the ND method. The most suitable approach for this purpose seems to be relatively simple recording of basic driving parameters in a large and representative sample of drivers from different countries. Such monitoring would provide a very important input to the database of the European Road Safety Observatory ERSO (cfr. the EU projects SafetyNet and DaCoTA).

2.8.3 In-depth accident investigation

A possible application in commercial driving could be to collect data for potential accident investigations; in other words, an extension of the “blackbox” or EDR (“Event Data Recorder”) currently in use in some vehicle fleets.

2.8.4 Providing incentives for safe driving

Equipping vehicles with cameras and recorders could also be used as a measure to influence driver behaviour towards better safety, on the assumption that the awareness of the recording equipment will make drivers refrain from certain unsafe behaviours. A study by Wouters and Bos (2000) indicated that ‘vehicle data recorders’ in vehicle fleets resulted in an accident reduction of some 20 %. There is, however, a strong need for more evaluation studies assessing to what extent drivers change their behaviour just as a consequence of the recording equipment. It should be pointed out that this is an application where it is assumed that the presence of recording equipment may influence driving behaviour, whereas when using ND for research purposes effects of recording equipment on behaviour should be avoided. The information to the driver regarding the possible use of the data for sanctions may be a crucial parameter determining possible effects on behaviour. However, as mentioned above, the possibility of observer effects should be further investigated, for better understanding of the full potential of ND methodology both for research and practical applications.

3 Interests of potential stakeholders regarding research topics and applications

3.1 Potential stakeholders

Looking at the results and outcomes of a large-scale ND study, different potential user groups are identified. Knowledge gained from using ND driving studies can be applied in various areas. Below the potential of ND is discussed for the different application areas.

3.1.1 Insurance companies

The insurance industry will be among the ones which will benefit most from implementing ND methods. For insurance companies, a large-scale European ND study could provide information on the accident and injury risk for different groups of road users in different conditions. The ND study could provide insight into the risk-taking behaviour among different driver groups (age, gender, area of residence, driving experience, etc.). Also the study could provide insight into the risk of different behaviours (e.g. distraction, fatigue, or speeding) as well as the risk of different situations (e.g. weather, time of day, etc) or different driving styles (aggressive, gentle, etc.). This information could be used for setting of insurance premiums by user group and exposure and could be used as a marketing instrument. Examples might be discounts for females who do most of their driving in daylight, for administrative officials, for vehicles parked in garages, for family cars, etc. What is justified? Calculation of insurance premium based on engine displacement, engine power, number of seats, total mass, etc. What is best? ND is a method that can provide a sound background for making such choices. Dedicated studies based on existing ND data would be possible, provided the sample is sufficiently large to enable breakdown of crashes by user groups and conditions.

Insurance companies are currently engaging in evaluations of driver behaviour, in particular for young drivers where the premiums are particularly high, and offering discounts for safe driving practice. This good practice is determined by an in-vehicle monitoring device that looks at speed and acceleration measures in relation to known accident risks. Therefore, the industry appears receptive to using driving observations at a mass market level in order to promote safe driving with a correspondingly lower premium.

3.1.2 Automotive (supplier) industry

For (automotive) industry a large-scale European ND study could provide new and breakthrough information on people's day to day use of their vehicles. The enormous value of ND is in the unobtrusive nature of the observation, which allows observing natural behaviour. The uses of ND data are multifold:

3.1.2.1 Safety and injury reduction

Most interesting and useful information can be learned just by studying the driving posture during normal vehicle operation. We may know details about the 'driver envelope' in a 'static' condition but not necessarily in the 'dynamic' driving condition which are thought to be different. This information could help for example with ensuring that drivers do not drive too close to the steering wheel which may be a problem for the deploying airbag.

Another very useful purpose of naturalistic driving information is the typical driving posture in the context of the seat. For example, it is thought that as the distance between the driver head and head restraint increases, so the risk of whiplash injury increases accordingly. Therefore ND data could examine this issue and see what the reality is. The ADSEAT project (*http://www.vti.se/templates/Page____12231.aspx*) is currently using naturalistic observations to this effect on a small scale, but the potential for a larger cohort is evident.

ND data can also be used to study issues such as driver fatigue, and knowledge about the circumstances and preconditions of falling-asleep events could possibly help to determine where fatigue warning intervention may be required and the type of intervention that may be needed. During any large-scale ND trial, there are always likely to be traffic conflicts, incidents and near-miss situations. Such situations, although not welcomed, do provide an opportunity to study the casual factors in great detail and to look for trends and common pre-incident behaviours. This information can be used in system development for the prevention of such incidents and can therefore ultimately lead to a reduction in crashes and resulting road casualties.

3.1.2.2 Driver interaction with in-vehicle information and safety systems

New driver information systems have been developed that can inform the driver about road hazards ahead, the presence of vehicles in an adjacent lane or the local speed limits. Autonomous systems such as Electronic Stability Control (ESC) manage the vehicle dynamics when road friction would otherwise be exceeded or detect vehicles or pedestrians ahead and activate the braking system. Under development are safety systems that take advantage of communication technologies between the vehicle and infrastructure and manage the manner and timing of road users and vehicles passing through junctions. All of these systems appear to address known driving situations of risk, however there are no measurements of casualty reduction, except for ESC, and all of them rely on there being no introduced risks of distraction or over-compensation.

In order to achieve large improvements in safety, new systems must target the most important causes of crashes. It is commonly assumed that driver behaviour is a frequent factor in accident causation, either as a result of extreme driving (e.g. alcohol, speed, fatigue) or errors of perception, judgement or action. Many intelligent safety systems are designed to mitigate or eliminate these human factors by taking control of these elements away from the driver. But driving is a complex task, and such piecemeal modification of these subtasks can in fact cause more problems, as it degrades the coherence of the task as a whole. Moreover, new tasks introduced by technology (e.g. attending to GPS) can cause problems of mental workload or situation awareness, as the drivers seek to manage the systems rather than drive the car. To be effective the functionality of a safety system must address the most important causes of collisions in a manner that integrates closely with the driving task and does not introduce new risks. Accident analysis is sufficiently sophisticated to identify many of the circumstances leading to the crash, and better models and methods for classification and analysis are developed to understand the role of the driver; e.g. the Driver Reliability and Error Analysis Method DREAM (Warner et al., 2008). In retrospective crash reconstruction, driver behaviours can only be inferred from accident data, not conclusively identified. Intelligent safety systems are still limited in the manner in which they support the driver in terms of situation awareness and mental workload, mainly because such systems have limited knowledge of the driving context and the driver's intentions. The relationship between the normal driving tasks, accident causation and system functionality is poorly understood at the level of detail required.

Naturalistic observations offer the opportunity to observe driving behaviour which can be quantified and modelled much more closely than hitherto in order to develop more effective safety systems that will encourage appropriate driving responses,

3.1.2.3 Driver operation

The ND data can also help in looking at reach envelopes for controls for driving, information, entertainment, and safety/security. We could learn every detail, from how they steer and how they sit in their seat, to the use of new and traditional in-vehicle support systems (e.g. cruise control, radio, navigation, warning systems, etc.). When, how and how often are these systems being used? How does this influence driving behaviour? What are the safety effects? What other systems could be of support for the driver? More advanced data collection scenarios may be able to infer eye gaze direction and therefore provide valuable information regarding the amount of time drivers spend looking away from the road as well as where they are looking during this time, assisting with the design of dashboard layouts, heads-up displays and the like.

3.1.2.4 Human machine interface

Driver information systems are becoming more prevalent and more sophisticated. In many respects, they facilitate the driving task (in the case of navigation systems) and may increase driver efficiency (traffic information) and personal mobility. However, there is still a requirement to look at driver information systems from an HMI perspective. ND could assess issues such as distraction, inattention and eyes-off-road and could help to discriminate between good and bad information systems from an HMI perspective.

Ultimately, ND data can be used to look at the driver-vehicle-road interaction and to detect where deficiencies are evident. This use of data encompasses all of the above but looks at the system interaction as a whole rather than the individual elements. Good HMI suggests safe, reliable and efficient operation of the vehicle. The data can therefore be studied from a holistic point of view to distinguish good and bad examples of driver vehicle HMI.

3.1.2.5 Powered two-wheelers (PTW)

To study riding behaviour, *naturalistic riding* is as valuable as naturalistic driving is for car drivers. However, the gaps in knowledge about rider behaviour are by far larger than for drivers. Implementing instrumentation on a PTW is more challenging than in a passenger car, as there are additional limitations concerning space and power supply. Just as for cars, a wide variety of stakeholders will benefit from ND research ranging from manufacturers to the riders themselves. But also an ND study could significantly contribute to rider safety. In particular, the "looked but failed to see" problem, which is a very prominent cause of PTW rider injuries, is still unsolved and could be targeted using ND data. PTW behaviour can be studied both from the perspective of either the rider or the driver, and studies of the latter problem has to be based on observations of the drivers.

3.1.3 Public administrators and police

Public administration may have, considering the various tasks, manifold interest in ND studies.

3.1.3.1 Developing targeted safety measures

The design of road safety programmes may be improved by additional data derived from naturalistic studies. Decision makers need measures which have a demonstrated impact and which are accepted by road users. Within both these fields of interest, naturalistic research is beneficial. As indicated above, one of the major purposes of naturalistic research is the design of a new generation of road safety measures, which have so far not been identified or applied since the traditional methods of research did not succeed in making problems or solutions visible. It may also be the case that traditional methods did not succeed in assessing the impact of measures that are already known. On the other hand, decision makers may gain a broad picture of the extent of certain misbehaviours. Hence, measures which target misbehaviour of a small high-risk minority are more likely to be accepted by a majority. Measures requiring only small changes in behaviour might be more easily accepted than measures requiring a radical behavioural adaptation. Stepwise approaches towards safe behaviour could be facilitated.

3.1.3.2 Road construction and maintenance

Road authorities will benefit mainly from the traffic management element within naturalistic research. Road construction and maintenance can be better adapted to road users' needs. This addresses the layout of roads in terms of usability as well as decisions about building new roads, rebuilding existing roads or providing sufficient capacities just by minor adaptations of existing infrastructure. Enhanced knowledge about driver behaviour will, hence, assist road authorities in prioritising of investments.

Environmental impact could be considered within road impact assessment as soon as naturalistic research discovers relevant correlations between road layout, driver behaviour and energy consumption.

3.1.3.3 Traffic enforcement

Naturalistic driving research will also be beneficial for police forces as traffic material is required urgently. Naturalistic research will, on the one hand be supportive to determine most dangerous behaviours and the conditions under which they occur, and on the other hand allow for identification of the most efficient enforcement strategies taking respect of typical patterns of (mis)behaviours of road users. Particularly, where current methods of enforcement are not well developed or even absent, naturalistic research may pave the way towards accurate measurements. Aggressive driving is a case in point. As indicated above, fatigue is such a field, where there is currently no measuring equipment, but its impact is highly detrimental to road safety. The prevalence of fatigue, as well as distraction and inattention is widely debated in normal driving, yet they are believed to be relatively common amongst crash-involved drivers. All drivers experience traffic conflicts and near-misses. However, it is unknown how these unquantified experiences relate to risk perception and crash avoidance strategies in normal driving. These factors are directly relevant to road safety policies, safety campaigns and enforcement of road safety rules. Direct observations of driving behaviour in its normal social context will improve our understanding of critical driving events and the data will not only support future policies on road user behaviour but also open up new possibilities to improve safety by improving driver training and enforcement.

In terms of enforcement, naturalistic research will also be beneficial in terms of defining accurate fines. It is widely accepted that fines should be adapted to the risk exerted by a certain kind of offence, and naturalistic research will provide additional data to define such risks.

3.1.3.4 Monitoring road safety performance

Any policy relating to new road safety targets will be monitored and the availability of ND observations offers the opportunity to identify new indicators of driving safety which can be specifically related to driving behaviours. These detailed data will permit the derivation of measures of driving behaviour which will represent a wider part of the driving population. The occurrence of higher risk behaviours is a target of casualty reduction policies, and indicators of these behaviours are expected to change as a result of road safety interventions. The availability of the detailed behaviour data will facilitate the development of in-depth driving indicators and new ways to monitor traffic safety progress.

3.1.3.5 Managing vehicle emissions and fuel economy

There is a need for more realistic duty cycles to standardise and validate low carbon power systems; however there is a surprising absence of quantitative data on the use of cars in real-world conditions that can be used to derive new duty cycles appropriate for hybrid and plug-in electric vehicles. To derive new duty cycles it is necessary to directly follow and monitor the vehicles and examine the driving behaviour and traffic congestion, and the impact on CO_2 emissions using detailed energy and emission models and linking them to real-world driving patterns and traffic conditions. Naturalistic driving is the obvious tool to derive these data.

3.1.4 Research

There is a range of highly relevant topics in the areas of road safety, eco-driving and traffic management which are very hard to investigate with existing methods. Topics like fatigue and distraction (inside or outside the vehicle) are considered as increasingly contributing factors to crashes. So far, experimental research has provided some understanding; however, naturalistic driving observation would allow for unobtrusive observation of real driving behaviour and as such much more reliable and valid results on exposure to those risks as well as understanding those behaviours. Thus, all topics and questions where the ND approach is likely to add to current knowledge are interesting from the research stakeholders' perspective.

3.1.5 Driver training and licensing agencies

A large-scale European ND study could provide better understanding of driver behaviour, learning processes and development of driving skills. The crash risk of young and/or novice drivers quickly jumps up after the end of the supervised driving, and then drops substantially in the first months and years after licensing. However, it is still unclear what and how a driver learns in this initial period of independent driving.

A study like this would allow observing drivers during their training but also afterwards and monitor their learning curves in terms of their unsafe behaviours and the critical crash indicators. Also it would allow identification of driver characteristics that are related to different driver and risk taking behaviours. Knowledge from this study could be used to improve driver training and/or licensing.

Naturalistic data can be used to develop and assess methods of training and retraining, of graduated and multiphase training approaches. Further, naturalistic research could be used to design and further develop simulator training methods. In this respect, it is again the differences between conflicts, near misses and collisions which appear to be of critical importance. Those involved in the development of training methods still do not have an adequate picture of how young drivers and other novices behave right after training and licensing. Neither are there methods available to assess the impact of different methods of driver training either in the period right after licensing or later on.

In general, driver training will benefit from additional knowledge about how drivers are functioning and how different tasks are organised by young, experienced, or elderly road users.

3.1.6 Expert witnesses and legal system

Expert statements supporting the state attorneys and courts are to a large extent based on witness statements. Such statements include individual subjective evaluations of events, like a passenger crossing the road "slowly", "quickly", "fast", "running", etc. The expert witness has to transform such personal impressions of a witness into mathematical terms, i.e. walking speed in m/s. The same goes for other events like duration of a lane change manoeuvre, curve speed, acceleration after an intersection and many other frequent manoeuvres. ND observation would allow getting more accurate information about typical values and distributions of these values under different conditions, potentially being linked with valuations by the drivers or other road users. Many of the tools and values have been gained by experiments conducted under laboratory conditions or are calculated based on mathematical models. Hence, real life data would mark a significant step towards more accurate ex-post assessment of collisions.

As a further field of particular interest, ND data can be used to determine reasonable or good driving behaviour. In particular the comparison of conflicts, near misses and actual crashes could provide valuable information regarding to what extent drivers are able to detect other road users' intentions and errors, to what extent they are capable of compensating for such errors, and which additional parameters the expert has to consider to prepare a court's decision about whether a road user is to be considered guilty of a collision or not. As an example, the question about whether a car driver should have directed attention to a pedestrian who is crossing the road should be answered by an expert witness considering vehicle and walking speeds, geometrical information about the road, walking direction and light conditions. Naturalistic research could significantly improve the tools and values available to experts for answering this and a wide variety of other questions.

3.1.7 Other

Road user organizations, environmental organizations, consumer protection and a large variety of other organisations, either governmental or non-governmental, either private or public, either profit or non-profit organizations could benefit from the insights from a large-scale European ND study.

The knowledge could provide them with better insights into the interests of the users they represent, the clients they want to approach, or the groups they want to protect, and could help to argue for certain measures or other changes, assess effectiveness and efficiency and approach relevant stakeholder supported by objective judgement.

3.2 Interests of potential stakeholders

3.2.1 Survey results

A survey was performed among members of the PROLOGUE User Forum to identify the areas of interest of the different stakeholders (van Schagen et al., 2010). A total of 72 people completed the questionnaire.

The sample may not be representative for the population of parties that are potentially interested in ND studies. In particular, industry was hardly represented. Therefore, the results have to be considered as an indication only. However, there are only minor differences in the interests of the different organisation types and between respondents from different groups of countries. Therefore, these indications can still be considered to give a fairly complete picture.

Within the area of road safety, risk taking behaviour, pre-crash behaviour, crash avoidance behaviour, and driver condition were considered the most interesting topics for naturalistic research. Many respondents also had additional suggestions for interesting topics for a large-scale ND study, such as visual attention of the driver, the effects of platooning, and the validity of performance indicators.

When asked whether the respondent's organisation was interested in contributing to a future large-scale European ND study, over 80% of the respondents indicated that they were interested in participating in such a study; 4% were interested in funding such a project and 10% were interested in supporting such a project effort though not in monetary terms.

All in all, it can be concluded that the potential users of ND studies have a broad interest. Almost all topics that were presented in the survey were considered to be (very) important by a majority of the respondents. Road safety issues were somewhat more popular than eco-driving and traffic management issues. This may be party explained by the over-representation of research organisations in the sample and by the fact that, based on experience so far, respondents associate ND studies mostly with road safety. The broad interest also turned out in the large number of answers to the open questions and in the willingness to participate in a future large-scale European ND study. A number of respondents were even prepared to fund such a study, at least in kind. Whereas there seems to be a wide interest, most potential users consider ND studies particularly useful for studying road safety and less so for studying environmental aspects and traffic management issues. It would be a task of the PROLOGUE project to clarify and show that ND studies also would provide very useful information in those areas.

3.2.2 Regional workshops

To further explore and understand the interest of the different stakeholders, within the framework of PROLOGUE six regional workshops were organised (Eichhorn & Van Schagen, 2011). The main objective of the regional workshops was to acquaint as many organisations and stakeholders (road safety, traffic management, industry and environment) as possible with the new approach of naturalistic driving (ND) and its potential benefits as well as to get their support for a large-scale European ND study.

The six regional workshops took place in Austria (German speaking countries), Greece (Greek speaking + simultaneous translation into English), Netherlands (Dutch speaking countries), Norway (Scandinavian countries), Spain (+ Portugal), and the UK, between October 2010 and February 2011. Since the regional workshops were held in the respective native languages and closer to the workplaces, they were assumed to have a wider reach than international conferences, in particular transport practitioners. In total, almost 200 people participated in the workshops.

Outcomes and recommendations from these events are:

a) All six workshops held can be considered a success; positive feedback and constructive discussions showed the high interest in the new methodology.

b) It transpired that a further clarification of ND will be essential for non-researchers in order to have a mutual basis for further studies.

c) Given that vulnerable road users are an issue in road safety research it is very important to include pedestrians and cyclists (as well as infrastructure) in ND studies.

d) The same applies for powered two-wheelers. Future ND studies definitely will be improved by the addition of instrumented PTWs.

e) The workshops showed that different research fields would benefit from an ND study. However, there will be a need (depending on the aims of the respective study) to integrate relevant variables e.g. for traffic management or environmental issues.

f) It will be a challenge to find sufficient numbers of subjects willing to drive an instrumented car over a longer period of time. Hence, incentives per participant (with various payment modalities) should be considered in a large-scale study.

g) Data use as well as data protection and ownership were raised at several workshops. It has to be defined if the data are owned by the person or the investigating institution and how the data-set will be used afterwards.

3.2.3 Stakeholder involvement

In the planning phase of a European large-scale ND study, an important challenge is to establish a good dialogue with the various stakeholder groups that have been listed in this section. This will serve several mutual purposes. First, it will provide the various user groups with more knowledge about the possible contributions and added value of ND observations to the respective application areas. Second, it will provide useful information to the research team regarding knowledge needs. Third, it will contribute to gaining support for carrying out a high quality ND study.

Altogether, stakeholder involvement is an important precondition for the study to produce useful applied results for stakeholders on the short term, and to provide good data for scientific investigations for long-term improvements of road safety as well as environmental and traffic management aspects.

PART 2: Methodological aspects

4 General overview of methodological requirements

Although naturalistic driving studies may focus on different road user groups, the description of the method in this document will use the driver as the general example, to simplify the presentation. Use of ND for investigating other groups of road users, as well as the interaction between drivers and other road users was discussed in Section 2.3.2.4.

ND studies vary with respect to several methodological aspects, such as sophistication of data recording, data encoding and reduction, and size and composition of driver samples. This is related to the research questions addressed in the respective studies. Some issues can be investigated by recording only a few variables, and with the use of relatively simple and inexpensive equipment, whereas other issues may require more advanced and high-tech equipment for providing the relevant data to test the hypotheses in question.

In this chapter we will present a general classification framework for specifying the methodological requirements to naturalistic observation studies of certain types of research questions and hypotheses.

The main dimensions in this framework are 1) variables to be recorded, 2) size of sample and duration of study, 3) special requirements to sample composition, and 4) data enrichment. These parameters will be discussed only briefly here, as a background for the general classification of research questions by methodological requirements. The four dimensions will then be discussed in more detail in subsequent chapters.

4.1 Variables to be recorded

In PROLOGUE deliverable D3.7 (Backer-Grøndahl et al., 2011) the following levels of data were differentiated, representing increasing levels of technological complexity:

- Basic driving parameters
- Event-triggered video data
- Continuous video data
- Specific additional measures

The most *basic driving parameters* include speed and acceleration (both lateral and longitudinal). Vehicle position (GPS) should also be included among the basic driving parameters. The basic driving parameters can either be recorded by sensors installed in the vehicle or by a nomadic device like a smartphone.

Video recording is an essential and innovative aspect of many ND studies. The most basic type of video recording is one camera on the driver's face and one on the traffic ahead. An additional video aimed at the dashboard, steering wheel, and the driver's legs may be used for measuring driver manipulation of controls. The video recordings may be activated by some event-based trigger, e.g. hard braking or acceleration, or an abrupt movement of the steering wheel, in order to capture the events (near miss incidents or crashes) related to the triggers. This will be referred to as *trigger-based video*. Alternatively, the video may be recorded *continuously*; this reduces the risk of losing important data, at the cost of increased storage space requirements.

The driver's pattern of visual fixations is a very interesting variable in studies of distraction and inattention. Although big advances have been made in the development of *eye-tracker systems*, it is still complicated and difficult to get valid data unobtrusively and without extensive calibration before each trip. In principle, eye-tracking data are derived from mixing the video images from the driver's eyes and from the road ahead, and indicating the driver's point of fixation by a mark superimposed on the road scene image. This is an example of a specific additional measure that could be added to basic driving parameters and video data.

A wide range of additional variables can be recorded from the vehicle, including activation of the various controls (steering wheel, gear, accelerator, brake, turn indicator, horn, ventilation, radio), status of displays and lamps, and engine parameters (rpm, load, fuel consumption, etc.). There is no sharp distinction between the basic driving parameters and the additional measures listed here.

Even more complex recordings may be interesting for some research questions, e.g. psychophysiological measurements, but since current technology does not enable unobtrusive recordings of such measures, they are not (yet) relevant for ND studies, although they can be used for experiments in real traffic with instrumented vehicles, which is an important supplement to ND studies.

4.2 Sample size and study duration

The amount of data that will be available is a function of both sample size and duration of data collection (in addition to the number of recorded variables and their sampling rate). Thus, kilometres, hours driven, and *vehicle years* are possible indicators of the amount of data for each measure that is being recorded. Large driver samples and many kilometres per driver are, however, not equivalent ways of increasing the size of the database. For some research questions large numbers of drivers are needed, e.g. when observed behaviour is studied in relation to driver or vehicle background factors, and the sample needs to be broken down by several factors. For other issues, a high total driving distance is more important, e.g. when the purpose is to study behaviour related to crashes and near-crashes. Some research questions can be investigated with relatively small amounts of data. For example, studies of driving style related to fuel economy does not require months and years of data, like studies of crashes, whereas a large number of drivers may be useful, in order to study factors that determine individual driving styles. However, even for research questions that can be investigated by short periods of data collection, the necessity of a minimum duration for drivers to get accustomed to (and forget about?) being observed needs to be considered.

When showing some examples below of how research questions can be classified according to methodological requirements, we will just use the categories *small*, *medium*, and *large* when referring to amounts of data needed. "Large" will imply several thousand vehicles with data collected for at least a year, whereas small may imply less than 100 vehicles with data collected for a few days only.

4.3 Drivers and vehicles

For some research questions a random sample of drivers or vehicles would be most appropriate, e.g. when the purpose is to investigate typical or average driver behaviour in certain situations. However, if the focus is on the relationship between driving behaviour and certain driver or vehicle characteristics, it may be necessary to recruit special groups of drivers or vehicles. For example, an interesting issue may be driving behaviour among driver groups that are over-represented among crash-involved or injured drivers, such as young, male drivers or elderly drivers. This would require sufficiently large numbers of drivers from these particular groups.

4.4 Data enrichment by additional information

Naturalistic driving data from drivers and vehicles may be linked with additional data sources, related to e.g. infrastructure, geographical information, traffic data, crash data, safety data (e.g. speed measurements, black spots) from driver, road and/or vehicle registers, and/or driver self-reports. For some research questions such data enrichment is a necessary precondition. For example, infrastructure information is necessary if the purpose of the study is to compare driver behaviour in different road environments. The previously mentioned possibility of combining vehicle-based naturalistic observation data with site-based observations e.g. of different types of intersections, is an interesting example of ND data enrichment.

4.5 A classification framework

Table 4.1 shows a few examples of how different research issues have different methodological requirements in terms of the above mentioned factors related to performance indicators, sample size and composition, and data enrichment.

Table 4.1; Examples of mapping methodological requirements to research topics and questions

	Research topic	Crash risk related to driver distraction and inattention	Eco-driving	Identifying risk factors and estimate their relative risk	Young driver risk-related behaviour	Conflicts between motorized vehicles and vulnerable road users
Parameters to be recorded	Basic driving parameters	V	V	V	V	V
	Event-triggered video data			V	V	
	Continuous video data	V				V
	Specific additional measures	V		V		
Sample size/ study duration	Small/short		V			V
	Medium					
	Large/long	V		V		
Special sample					V	
Data enrichment	Site-based observation					V
	Environment or infrastructure	V	V			
	Driver or vehicle data		V	V	V	

5 Design options: Sample size and different levels of equipment

Considering 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 size 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 e.g. 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

5.1 Advanced technology ND study

If all interesting research issues should be investigated by one single study, that study would have to be dimensioned according to the issues requiring the most advanced data recording alternative, the largest sample size and the most comprehensive data enrichment (referring to Table 4.1).

Designing a study following this approach would enable investigation of the most demanding research questions at the same time as other issues could be analysed by using subsets of the database. Such a study would have the following basic characteristics:

- An approximately random[4] stratified sample of several thousand vehicles/drivers, with over-sampling of certain driver/vehicle categories of special interest
- Continuous recording of advanced vehicle parameters as well as several video channels
- Eye-tracking
- Availability of vehicle, driver, infrastructure and traffic data to be linked with ND observations
- Data collected for at least a year per driver-vehicle

A considerable large-scale European study would certainly have great added value compared to previous research. Such a study would, however, imply very large costs, and it is therefore probably not feasible due to economic constraints. There are several alternatives for reducing the costs: 1) reduced number of vehicles/drivers, 2) reduced duration of data collection, and 3) excluding parameters requiring the most expensive recording equipment.

The first two alternatives are clearly preferable to the third. As long as the most advanced recording equipment is used, it is possible to extend the database later by additional data collection, and it is not a big problem if the first sample has to be reduced. On the other hand, if important parameters are omitted, later additional data collection will not help. A recommendation if one single study is to be conducted is therefore to

[4] Since participation in an ND study is supposed to be voluntary, any sample will necessarily be somewhat biased, and therefore a completely random sample is an ideal that can be reached only approximately.

prioritize advanced data collection to a large sample size and/or long periods of data collection.

5.2 A series of studies with different levels of recording technology

A less expensive alternative to one big study could be a series of smaller studies, each tailored to investigating a particular set of research topics. However, although less expensive, it may be questioned whether this is the most cost-effective approach in terms of providing new knowledge. It can be argued that the primary distinguishing characteristic of the ND approach is the possibility to address research questions regarding the relative risk of factors related to driver distraction, inattention, sleepiness, and other aspects of hypovigilance which require the most advanced (although expensive) study design.

5.3 Low-cost simple alternatives

Several basic driving parameters can be recorded by a smartphone, including GPS location, speed and *g* forces (longitudinal and lateral acceleration). It may even be possible to use the smartphone video camera to record either the traffic scene or the driver. A smartphone with two cameras would be preferable, in order to record both the forward view and the driver.

An alternative could be to include a simplified and low-cost video equipment, e.g. similar to the DriveCam system (® The Driver Science Company – *www.drivecam.com*).

Such devices can make it possible to conduct a large-scale study at a very low cost compared to the technologically most advanced system described in Section 5.1 above. The smartphone-based recordings may be enriched afterwards with any time or location based information, e.g. related to infrastructure, traffic conditions, weather, etc.

There are, however, some important limitations of a naturalistic driving study based only on parameters that can be captured by a smartphone. First, it does not provide information about driver actions related to car handling, such as gear change, steering movements, use of other controls, etc. Second, it does not provide information about engine parameters, fuel consumption etc, which are relevant for assessing environmental effects of driving. Additional data recording, e.g. from the vehicle CAN-bus, is necessary to get these types of information. Third, the video recordings of a smartphone may not provide sufficiently detailed information, neither regarding driver visual behaviour nor from the traffic environment.

It seems, therefore, that smartphone-based technology may not be sufficient for a naturalistic driving study with the purpose of studying the most important research issues related e.g. to driver distraction and inattention. The most appropriate applications of smartphone technology related to naturalistic road user observation seem to be:

1) Recording of basic parameters for monitoring of traffic safety indicators rather than research.
2) Since the smartphone is independent of the vehicle, it seems ideal for recording traffic behaviour of other road user groups, such as vulnerable road users, and for recording behaviour across transport modes. Thus, one can investigate mobility more generally, and not limit the study to driving behaviour.
3) It may be used as a supplement to a more comprehensive naturalistic driving study, both for quick access to basic data, and for the purpose of validating the smartphone for monitoring purposes. The smartphone can be a sensor, data logger, storage unit, and transmitter to database in one device.

Since the technological progress is expected to continue also for smartphones, the state-of-the art should be closely monitored in the planning phase of a large-scale study, in order to assess the potential of this alternative to a more expensive study.

5.4 Combining different technologies

An option for a large-scale study could be a design with different levels of technological sophistication for different sub-samples. A very large sample of vehicles (several thousands) could be equipped with relatively simple technology for recording basic driving parameters. This could be achieved by using smartphones, including GPS, accelerometer and video. Relatively simple technology would be sufficient e.g. for the purpose of long-term monitoring of road exposure data and safety performance indicators, as described in the DaCoTA project (Talbot et al., 2011)

For sub-samples recording of basic driving parameters could be supplemented by trigger-based recording of driver and forward video as well as additional vehicle parameters, e.g. from the CAN-bus, in order to record predefined incidents.

For investigating specific research questions additional dedicated equipment could be added for smaller sub-samples. For example, eye-tracking and high-resolution video would be relevant for investigating driver visual search as well as distraction and inattention. And recording fuel consumption may be relevant only for studying environmental effects and not for safety; consequently the relevant parameters for this topic could be included for a smaller sub-sample only.

6 Indicators of driver performance and critical events

6.1 Indicators and measures

The main aim of naturalistic driving observation is to observe driver behaviour that may be relevant to safety, mobility and/or traffic management issues. For this purpose it is essential to define the relevant indicators of behaviour – termed *performance indicators (PI)*. Furthermore, driver behaviour has to be studied in relation to certain *events*, which also have to be defined – we choose to define them by *event indicators (EI)*. Events may be crashes, near crashes, traffic conflicts, or other potentially safety-relevant incidents. Finally, the behaviour and events may take place in different situations; therefore a list of *situational indicators (SI)* has to be included as well. The different indicators are derived from the *measures* that are recorded during the drive – examples of measures are speed, acceleration, lateral position, headway, point of visual fixation, steering angle, etc.

The choice of indicators and measures for a given analysis will depend on the particular research issue that is being investigated. Considering also the desirability of being able to investigate new research questions post hoc (see Section 2.1) the list of interesting indicators and measures will also be rather comprehensive. In this chapter we will list indicators that have been used in previous ND studies – including the PROLOGUE field trials – as well as additional ones based on the research topics suggested in Chapter 2. In listing measures and indicators we will give examples of related research questions.

The measures are the basic data, from which different indicators are derived, either in real time or during analyses of the resulting database. A given measure may be used for the derivation of different indicators: e.g. eye movement variability may be an indicator of fatigue, distraction, and alcohol impairment. Also, several measures may be used in combination to define a single indicator. In this section we will focus on the measures, since they are an integrated part of the data collection, whereas the indicators (derived from measures) will vary depending on the type of analysis and the research question that is analysed. The following list of measures is based primarily on PROLOGUE Deliverable D-2.2 (Groenewoud et al., 2010). We refer to this source for an extensive list of driver, vehicle, road and environment variables that are relevant for inclusion in ND studies.

6.2 Driver-based measures

Despite the fact that driver behaviour is the main focus of ND research, only few measures are observed by directly recording what the driver does. Many studies include only indirect observations based on vehicle measures (see Section 6.3 below).

Video recording is the most widely used driver-based measure. There are several alternative video views that may give useful information of driver behaviour. Face and eye video is important for deriving indicators of attention, distraction and fatigue. Video of the driver upper body yields data for investigating e.g. seating position.

Another important driver-based measure is speech recording, which can provide useful additional information about circumstances of crashes and other critical incidents, especially when coupled with videos.

Physiological activity also allows opportunities to record interesting measures, related to alertness, fatigue, stress, mental load, etc.[5] However, it is very difficult to measure

[5] Although very difficult to measure unobtrusively at present, physiological measures are included here as a future possibility.

physiological activity unobtrusively, and such recording is therefore presently limited to non-naturalistic research with instrumented vehicles. Developments within psycho-physiological methodology should be monitored regarding future possibilities for unobtrusive recordings of some physiological measures.

6.3 Vehicle-based measures

Most of the measures of driver behaviour are vehicle-based, i.e. 'vehicle behaviour' reflects driver behaviour. The most easily (and most frequently) recorded measures are speed and acceleration. In addition, there are a lot of additional measures that are very important for understanding driver reactions in crashes and incidents as well as during normal driving, e.g. gear position, brake force, and steering wheel movements. Several measures, including status of most actuators and sensors, which may indicate various aspects of car handling behaviour, are available from the CAN-bus, a fairly standardised “signal processing system” for motorised vehicles.

6.4 Environmental, situational and infrastructure measures

There are several measures for deriving indicators of the environment, the traffic situation and the roadway. The location of the vehicle is indicated by GPS coordinates, which is a must in all ND studies. Time is another important measure, both for comparisons of various time periods (time-of-day, weekday, etc.), and for synchronisation of different data sources.

Forward video is a very important measure for identifying various aspects of the road and traffic situation. Additional video measures are rear and side views. Several road parameters can be identified from the videos, such as number of lanes, type of road, presence of barriers and guardrails, driving in tunnels or on bridges, road curvature, etc.

Weather conditions are also important and can be analysed based on measures such as air temperature, precipitation, humidity, visibility, or barometric pressure.

6.5 Different levels of measures

The measures listed above are variables that will normally change during a trip. In addition there are variables that are constant for a whole trip, which are also relevant, e.g. length and purpose of the trip, carrying passengers, etc. Trip length can be recorded automatically. Possibilities for recording additional information should also be considered, e.g. an easy logging system where the driver is asked to supply some basic information at certain intervals.

Finally, there are trip-independent measures that are recorded only once for each driver/vehicle combination, which also needs to be matched to each trip record.

Addition of further variables is discussed in Section 9.5 on data enrichment. In principle, any variable that has a location and time identifier can be linked to the database afterwards, depending on the research question to be investigated.

6.6 Relationships of measures to indicators and to research topics

A few examples will show how measures are related to indicators and how the indicators can be used for analysing research topics.

- Indicators derived from driver video may include head movements or eyeblinks for studying fatigue, inattention/distraction or looking behaviour. In combination with forward video, the eye video may also be used to derive indicators of visual fixation.

- Video measures may be used to indicate hand position for investigating some aspects of vehicle handling.
- An indicator based on brake force could be frequency of braking, for studying driving style or eco-driving.
- An indicator based on gear position could be frequency and timing of gear changes (e.g. in relation to engine speed and load), for analyses of eco-driving.
- Distance to the vehicle in front, in combination with speed, may be used to define an indicator of tailgating, e.g. time gap below a certain threshold. This may be related to research on aggressive driving. Changes in the distance to the vehicle in front can also be used to derive time-to-collision, which is an interesting crash-related indicator that should be investigated in relation to several background factors.

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7 Driver sampling and recruitment

7.1 Random vs. targeted sampling

The strategy for drawing samples and recruiting participants to ND studies depends on the research questions. If the purpose is to investigate typical and general aspects of driver behaviour, it is important to obtain a sample that is as representative as possible for the general driving population. On the other hand, some research questions may require samples comprising certain subgroups of drivers, e.g. if the focus is on the relationship between novice driver skills and crash involvement, a sample of novice drivers is necessary, or if age-related impairment is a topic, an older driver sample is required. Since we are proposing recommendations for a large-scale study with the purpose of investigating a wide range of research topics, a combination of random sampling from the general driver population and targeted sampling based on specific characteristics of drivers or vehicles is recommended.

It can be argued that if a random sample is sufficiently large, it should offer the possibility to investigate research questions related to particular sub-groups by applying the relevant selection criteria to the large random database. The necessity of over-sampling certain driver/vehicle groups to begin with should be ascertained after the size of the random general sample has been decided, and the expected sizes of different sub-groups in this sample have been determined.

7.2 Sample size and duration of study

The total sample size has to be dimensioned on the basis of the research questions requiring the largest sample sizes. The most demanding issues in terms of sample size seem to be estimation of relative risks associated with various aspects of driver behaviour. Since estimation of relative risks is one of the most important and unique contributions from ND studies in road safety research it is recommended to use this criterion for determining sample sizes.

Estimations of relative risks involve comparison of certain performance indicators between crashes and baseline driving. Thus, the final database (in terms of time or distance of driving, or vehicle years) has to be sufficiently large to contain a number of crashes. The amount of vehicle kilometres or hours with data is a function of both the number of drivers and the duration of the study. Preferably, both these parameters should have large values. Large numbers of drivers are important for generalisation as well as for selecting sufficiently large subgroups. Furthermore, a large average driving distance or time per driver is important to observe crashes and crash-related incidents even for subgroups of drivers.

In this document we will not recommend exact figures for sample size and duration, since this will depend on several specific design considerations that will be part of the specific study in question. However, in order to yield substantial added value compared to existing research, a large-scale study will imply a driver sample of some thousands of drivers and a data collection period of a year or more.

A computation example will indicate the amount of data needed in order to get a sufficient number of crashes for estimating relative risks. Let us assume an average crash rate of passenger cars of about 1 crash per 150 000 vehicle kilometres (including all severities, the majority being PDO crashes).[6] When analysing crashes it is desirable to be able to break down the crashes by crash type/location and by subgroups of drivers.

[6] Norwegian data for crash reports to insurance companies as well as Austrian data indicate that this is a reasonable assumption.

Let us therefore assume that we need one thousand crashes in order to perform the necessary estimations of relative risks. This would require a database of 150 million vehicle kilometres. Such an amount of exposure may be obtained from 1500 drivers driving 10 000 kilometres each, which means driving for about one year. If we make allowance for the possibility that volunteers for an ND study have a lower-than-average crash rate, it may be necessary to double the number of vehicle kilometres.

For comparison, the 100-car study yielded data for about 3.2 million vehicle kilometres and 69 crashes. The heavy-vehicle study by Olson et al. (2009) represented 5 million vehicle kilometres and 21 crashes.

It can be argued that relative risks can be estimated on the basis of near-crashes and conflicts instead of on real crashes. This was actually done to a large extent in the previously-mentioned studies (analyses were made on crashes and near-crashes combined). However, one of the big questions that a large-scale study could help answering is whether near-crashes and conflicts are appropriate proxies for crashes. Therefore, the estimates of relative risk so far only beg the question.

Thus, the necessity of finding the most appropriate crash proxies, which may subsequently be used in smaller studies, is a further argument for a very large total sample in a large-scale European study, although this total sample could consist of several subsamples with different levels of observation technologies tailored to specific research topics.

7.3 Recruitment, remuneration, and incentives

In order to get drivers to volunteer for an ND study, it may be necessary to offer some kind of benefits to the drivers. One possibility is to pay each driver a fixed amount of money per month during the period when the recording equipments is installed. For example, in the 100-car study, drivers using their own cars received a compensation of $125 per month and a bonus at the end. The bonus is probably important to prevent drivers from discontinuing their participation.

The attractiveness of participating may also be increased by giving the drivers the opportunity to receive a summary of the data from their vehicle after the study.

In addition to positive incentives, the absence of disincentives is also important. Care should be taken to avoid practical problems for the driver in terms of e.g. malfunction of equipment, interference of recording equipment with normal functions of the vehicle, etc. It is therefore imperative that the data acquisition system (DAS) be thoroughly piloted and tested in advance for all the vehicle makes and models to be included.

The procedures for data uploading should involve a minimum of effort on the part of the driver.

If a participant uses his right to withdraw from the study, all data for this participant must be deleted if required by the participant. If he/she accepts that the data are included in the study, it will be up to the research team to decide whether or not to use the data in further analyses. In any case, such data have to be identified by a special code in the database. A pool of "standby" participants should be recruited for the purpose of quick replacement of drivers that withdraw from the study.

It is recommended to establish a website for potential and actual participants, as initiated within the SHRP2 project (*http://www.shrp2nds.us/index.html*).

7.4 Geographic area

A large number of potential issues related to the geographic location of an ND study can be identified. The selection of geographical area(s) must be based specifically on the objectives of the study, and in particular in relation to the validity of the data that are being collected. There are three aspects that should be considered in this context:

The first point is to consider the geographic aspect in terms of the overall objectives of the study. Should certain geographic areas be considered because of characteristics that are particularly relevant to the research issues that are investigated? Various factors related to geographic location may be interesting independent variables in the study.

The second major consideration is that of generalization of the results. In particular it is necessary to ensure that data collected during a specific study can be generalized to the wider population of interest.

The third factor to consider is whether the geographical factor is of particular interest in terms of data analysis. If it is desirable to analyze results according the presence or absence of a particular factor, then the geographical environment(s) must include that factor (and possibly variations thereof). An example would be an investigation of the use of travel-related information to a driver. A research hypothesis may suggest that the use of this information would depend on the amount of other value-adding information available in the environment – for example that navigation-related functions are particularly valuable in rural areas with relatively few signposts. The study would therefore need to include those rural areas, and non-rural areas for comparison.

7.5 Privacy protection, liability, legal and ethical issues

Recording the behaviour of drivers who can be identified raises several ethical and legal issues related to privacy protection. In order to obtain data that give a correct reflection of naturalistic driving behaviour, it is necessary that the participants feel confident that the results cannot be used to compromise them in anyway.

Signing an informed consent form is always necessary for participants in such a research study, and it is important that the potential participants are given all relevant information before signing the form. Examples of informed consent forms used in the 100-car study are included as appendices in PROLOGUE deliverable D2.2 (Groenewoud et al., 2010). An example of participant information for the SHRP2 ND study is included as Appendix 2 in the present document.

It is obvious that drivers should have the right to withdraw from the study at any time. In such cases, they should also have the right to require all their recorded data to be deleted. It may also happen that a driver would require parts of the data to be deleted.

The legislation regarding various aspects of privacy protection may vary between countries, and for a pan-European study it may be necessary to adapt the procedures somewhat differently to comply with different legislations.

An important issue is whether data from ND studies can be used for legal prosecution in the case of violations or crashes that are investigated by police and/or insurance companies. Both for the purpose of recruiting participants and for obtaining valid and representative driving data it is essential that drivers can be guaranteed that data shall not be used for other purposes than research, and that no third-party will have access to data that can enable identification of individual drivers. The relevant legislation in the different countries has to be consulted. In the 100-car study, protection of driver privacy in the case of a crash was secured by provision of a Certificate of Confidentiality, issued by the National Institute of Mental Health (NIMH). The purpose was to prevent data from the study to be used against a participant in court.

Normally there will be one registered primary driver for each vehicle enrolled in the study. Since a vehicle may be driven by other drivers, who are not taking part in the study, there must be reliable procedures to identify the driver and to take care that data will not be collected for incidental drivers. Driver identification is of course also essential for the validity of the recorded data. The need of reliable driver identification was an important lesson learned from the field trials of the PROLOGUE project, where there were some cases of data loss due to missing driver identification (Backer-Grøndahl et al., 2011).

The issue of privacy protection of passengers must also be considered. This could mean that video recordings do not cover passengers. Another possibility is to have a sign inside the vehicle with information that the vehicle is video monitored. On the other hand, such conspicuous information may conceivably also reduce the “naturalistic” aspect of the driving situation for the driver as well. Therefore, further methodological research would be needed in order to provide more specific recommendations regarding passenger privacy protection.

Although sound recordings would be a very interesting variable from a road safety point of view, it raises considerable privacy protection issues. Sound recordings indicating only absence or presence of speaking, and other sounds, without disclosing verbal contents, could be a way of satisfying the privacy protection requirement, while still providing useful data.

7.6 Summary of recommendations related to sampling

To summarise the most important recommendations related to procedures for selection of vehicles and participants, some of which have been discussed above, we include the following list from PROLOGUE Deliverable D2.2 (Groenewoud et al., 2010).

- Create a large and diverse subject pool
- Choose vehicle makes that are popular
- Avoid geographical areas with relatively small populations
- Have a small number of “standby” participants to replace drivers removed from the study
- According to socio-economic factors, make sure that there is heterogeneity among the participants or make sure that there is a random sample that represents the driver population in focus
- Decide at an early stage whether or not to include drivers with vision or hearing impairment (“working for all” versus reducing confound risk)
- When a study concerns in-car devices that may cause distraction from the primary driving task, ensure that participants are experienced drivers (moderate to high-mileage drivers)
- Be aware of a possible ‘funnel effect’ (increasing inclusion criteria results in shrinking of the participant population) when it comes to selecting on personality traits
- When studying driver characteristics, keep in mind that an ND study is voluntary, which means that this self-selection can have a biasing effect
- Find out if you need to consider a particular geographical aspect because it is relevant to the research issues
- Find out if a geographical aspect needs to be considered to ensure that the results obtained can be generalized to the wider ‘population’ of interest (i.e. external validity)

PART 3: Data

8 Data acquisition

8.1 Introduction

Data acquisition refers to the specification and installation of technologies and the collection and transfer of data. This technology should, above all, be seen as a tool to answer proposed research questions. It is likely that no single piece of equipment will satisfy this brief and that simultaneous use of multiple technology types will need to be used. This section introduces the absolute recommendations, based primarily on PROLOGUE deliverable D2.1 (Welsh et al., 2010). Technical details are partly omitted and interested readers are referred to Deliverable D2.1 for a more technical and detailed presentation. Over time technology will continue to advance at a rapid rate; there will be better ways to answer research questions in very short time periods (take for example the technical improvements since the 100-car study to the current SHRP2 study).

8.2 Data acquisition system (DAS) specification

Many different systems have been used in ND and FOT studies so far, and there is a continuous technological progress in the direction of smaller, less obtrusive, and also less expensive recording equipment. Therefore, we do not consider it appropriate to recommend specific types or brands of recording equipment, since such recommendations are likely to be quickly outdated by the technological development. Rather, we would point out some desirable characteristics of recording equipment, based on a consideration of the most important measures and performance indicators in ND studies.

The following groups of recording equipment are fundamental elements of a DAS that is to be used for ND observation studies:

- Interface to vehicle data (CAN-bus etc)
- GPS-based system for continuous storage of position
- Continuous or event based video footage from multiple angles.
- Time code synchronisation between all data channels

Alongside these fundamental elements the technology should:

- Record unobtrusively
- Have sufficient data storage capacity and/or,
- Provide for easy data transfer
- Be reliable in protecting against data loss
- Have a reliable system for driver identification for every trip, with a minimum of effort on the part of the driver

Some additional desirable features of the DAS should also be mentioned:

- The system should preferably be integrated, so that all parts of the system are synchronized and data are saved to a common storage system
- Installation and de-installation should be as easy and flexible as possible; including the possibility of removal of components for repair

- Video image resolution should be sufficient for allowing identification of objects in the traffic environment, like signs etc.
- Possibilities for sound recording should be available (provided that contents of conversations can be masked for privacy protection)

In addition it is essential that all phases of the ND study should be tested in small-scale pilot studies before the real data collection starts

Whatever the technology used it should be able to integrate a number of different levels; these levels could include data on vehicle behaviour, environment, infrastructure and safety amongst others. To satisfy the requirements of answering a particular research question the most complex technology incorporating all these data levels is not always required, as simultaneous use of multiple types of technology can be used to good effect. Figure 8.1 shows the types of technology in question and some typical data groups.

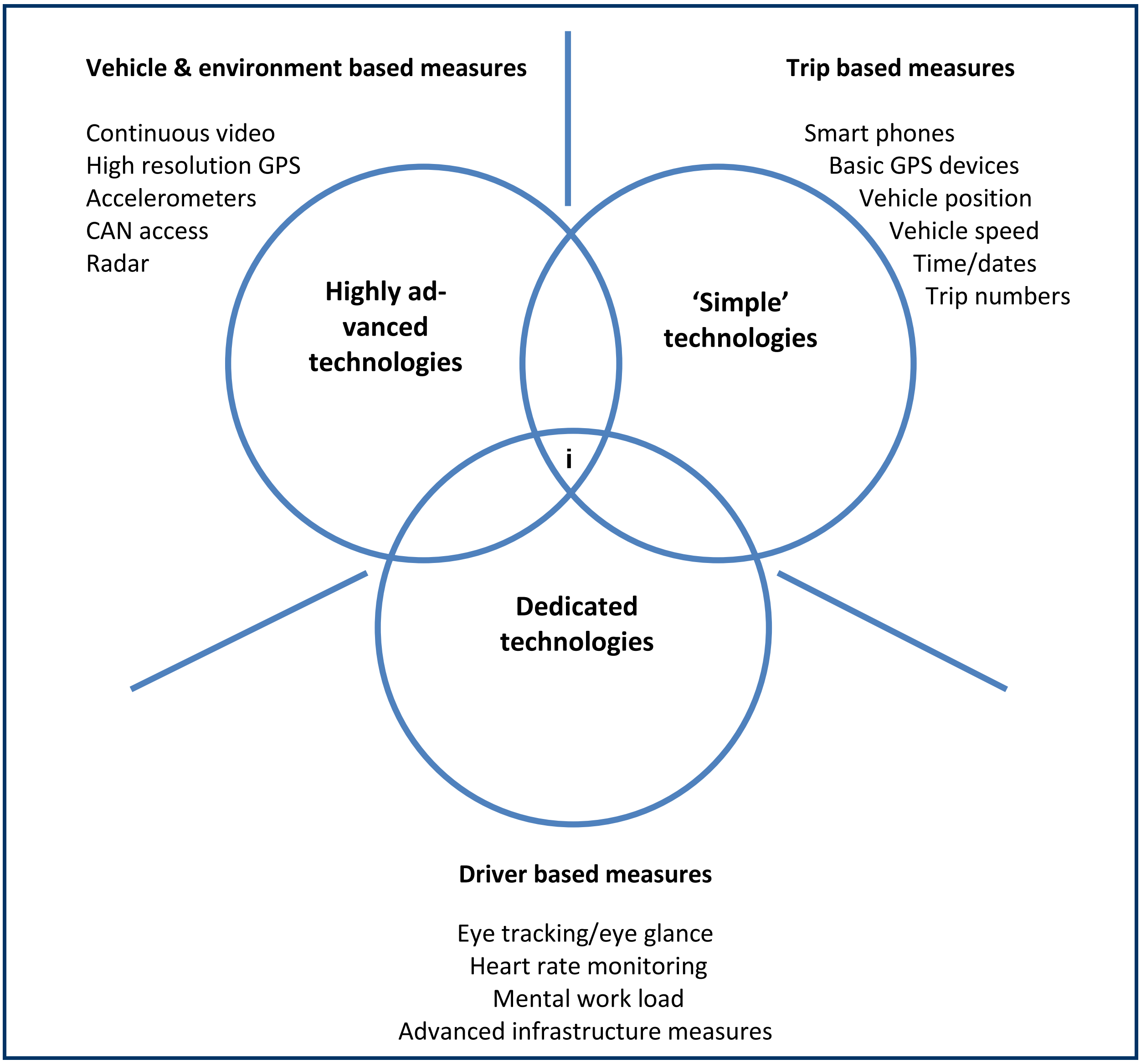


Figure 8.1 Technology and data groups

The types of data collected for each group are included in the headings in Figure 8.1; for example 'simple' technology will be particularly good at measuring journey-based data such as how fast the vehicle was travelling, how long a trip was, how many journeys are taken or where the vehicle went. Anything more than this, such as how often an acceleration threshold was exceeded or whether the driver uses daytime running lights will be answered by another data group – in this case in the vehicle- and environment-based measures.

Simple data groups are ideal for use in participant owned vehicles requiring little or no modification and very little user interaction. Where highly advanced and dedicated technologies are required the usual approach calls for dedicated vehicles, this method allows researchers access to the equipment for servicing, repair and calibrations to ensure good data quality. Using these technology groups in a more naturalistic way will entail greater development time and costs and particularly rigorous data security and management; this approach can be best seen in the SHRP2 study.

By moving through the data groups so the cost, complexity and ethical considerations increase, it is not always necessary therefore to specify complex technologies if the research question is simple. The centre of the Venn diagram in Figure 8.1, denoted by 'i' shows where the most complex and complete solutions to answering research questions lie – this is not always desirable as the value of the equipment can easily exceed the value of the research and the added complexity can present as many questions as those hoping to be answered.

- Technology should be tailored to the research question and not the other way around
- The value of simple data collection should not be ignored
- It is not always necessary to specify complex technology if the research question is simple
- Simultaneous data collection from different groups should be considered where possible
- Integration of dedicated technologies creates the greatest challenge but can also provide the greatest reward if well managed

8.3 Requirements for DAS installation

Installation of the DAS is a major consideration within an ND study. Inappropriate or incorrect installation of the DAS can render the data that are captured from field trials relatively ineffectual, so it is important that it is relatively precise from the outset. Piloting of the DAS is an important prerequisite.

Some basic principles that should be observed are as follows.

- The DAS should be unobtrusive and difficult to tamper with.
- The device should be installed out of sight of the driver.
- Consideration should be given to the need to remove or repair the DAS.
- 'Modularisation' of the DAS is another consideration - this would facilitate the removal of individual components for replacement and repair.
- Some DAS systems rely heavily on battery power which may need frequent replacement – access to batteries should therefore be relatively easy
- Provision of an internal battery backup system should be made to power the system when the vehicle is turned off and when the data are being downloaded

- The inclusion of a software switch that turns the DAS off from the voltage of the car battery/ inclusion of a "suicide" feature that automatically shuts the DAS down when the vehicle is turned off are further safeguards but should include good sensors and robust system shutdown algorithms.
- The entire DAS should operate under the normal driving conditions for the specific ND study including harsher conditions of normal driving.
- When controlling power supply to the DAS, the start-up and shutdown speeds must be optimised to reduce the loss of data.
- The physical connectors should be regularly checked to avoid detachment of the connectors
- If CAN data are required, attachment of any equipment to CAN-bus systems has to be done very carefully in order to avoid damage or injury.
- The installation should be such that the DAS should not interfere with the engine management system.
- To ensure data validity and quality, a calibration and verification scheme is recommended.
- When using a video DAS, direct real time observations should be carried out with great care and as unobtrusively as possible to minimise the risk of the driver modifying his/her driving behaviour. The number and resolution and views captured by the cameras should be sufficient to address the hypotheses and research questions.
- Pre evaluation of video image quality should be undertaken.
- If there is a need for in-vehicle data storage, it may be necessary to apply compression algorithms. Both data loss and the risk of error and/or malfunction of data acquisition have to be considered.

8.4 Data transfer

It is also necessary to transfer the data stored in the vehicles to a central database for analysis in a way that minimises data loss whilst disrupting the participant as little as possible. To ensure this it is recommended that the following basic principles are followed.

- There should be an adequate data management procedure with clear roles and responsibilities. This helps ensure that data transfer occurs prior to the in-vehicle storage capacity being exceeded.
- Multiple data backups should be undertaken prior to deleting data from the in-vehicle recorder and ideally data backups should be stored at different locations.
- Ideally wireless technology is recommended for data transfer as this requires minimal interaction with the participant. This can be done either via GPRS or by the vehicle passing through a wireless hub as part of its routine.
- Wireless technology however is not currently suitable for transfer of high-resolution video data. In this case data are transferred either typically by removable media replaced by the participant and sent to the central data collection location, or by a researcher visiting the participant to retrieve data.
- In all cases, but particularly with wireless data transfer, it should be verified regularly that the data 'sent' equates to the data 'received'.

9 Data analysis

9.1 Methodology for analysis

The FESTA Handbook lists a number of functions that need to be provided by the chosen software and hardware to support data analysis [p84]:

- 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)
- Export results function to tabular format or statistical packages.

The Handbook recommends that a number of software packages should be utilised to form an analysis package. One example is using SQL software for database queries. For computation, mathematical software such as Matlab could be used, and for statistical analysis, widely used statistical analysis applications would be appropriate (e.g. SPSS). It also suggests that custom solutions (proprietary) with user friendly graphical interfaces may be most appropriate for the analysis of large and complex datasets.

The Test Site Sweden FOT (SAFER, 2008) used a similar variety of tools in their analysis software package. Database query, video and annotation tools were developed separately from graph functions and calculation functions. A database search interface was developed for the project using the SQL.

Custom software was developed to create an interactive viewer and annotation tool that allowed the viewing of video and numerical values and manually adding annotations to data. The aim was to utilise, wherever possible, existing applications. The different tools were designed to interact to appear as one analysis package.

The Test Site Sweden FOT report gave the most detail about the software they used for data analysis as most of the literature concentrates on the analysis methodologies. However other study reports give some details of some aspects of their analysis. Data reduction/event identification and conversion of that data into other formats for more detailed data analysis was the most common processes to be documented. Stutts et al. (2005) report that video data were coded manually by researchers viewing the video. Once this was finalised it was converted into a SAS data file to allow in-depth analyses including statistical testing. Barr et al. (2003) state that a specific software program was used to perform eye glance data reduction. Lee et al (2004) report that a lane change data integration and analysis program was developed to support data analysis. This program combined data from the many data sources including video, radar, sensor and additional data that had been entered in an Excel spreadsheet. Data packets were available for statistical analysis once events had been identified, categorised and entered into the program. The team at VTTI used basic statistical packages to analyse their large datasets (such as SAS and SPSS) although the derivation of the data to be analysed is made through a data reduction process since the "core" data set itself comprises several hours of video footage.

9.2 Data reduction

Basically, the data reduction procedures lead to the extraction of specific events and measures. The end product (i.e. the data to be analysed) comprise specific signatures that indicate that an event in the driving process has occurred. The signatures themselves are identified through the application of specific criteria (acceleration/deceleration, swerve, etc) that are applied to the data downloaded from the data loggers.

The 100-car study gives the following advice regarding data reduction. The data reduction process for this study was developed to record epidemiological data, similar to the General Estimates System (GES) crash database of NHTSA, as well as record data that has typically been collected in other instrumented vehicle studies, thus greatly augmenting both types of data collection. The five channels of video were primarily used to record these variables. However, the data reduction software, developed in-house, allowed the data analysts to access time plots of the various vehicle sensors (i.e., longitudinal deceleration, vehicle speed) and could be used to record certain other variables as well. Even with driving performance data and video greatly enhancing the data reduction process, many reduction variables still required a judgment call or subjective analysis. Many steps were taken to ensure inter-rater reliability and reduce subjectivity for these types of variables. Test results indicated that there was 88 percent inter-rater reliability for validation of events and 99 percent intra-rater reliability for recording all of the reduction variables.

Incorporating five video channels into the 100-car study DAS was done to ensure the capture of as much of the drivers' view surrounding the vehicle as possible (forward view, rear-view, rear-facing passenger window, and outside the driver's window), as well as driver behaviour. There are trade-offs associated with these five camera views, which include size of video files and resolution of the video. Five channels of video increased the bandwidth of the video data, which forced VTTI engineers to decrease the level of resolution of the video so that storage issues would not become problematic. However, the resolution level provided by the system still allowed eye glance reduction to be performed. The resolution levels had a higher effect on discriminating objects and obstacles outside the vehicle. Potholes, for example, were very difficult to identify. Street signs (i.e., speed limit signs) were not readable. Objects inside the vehicle were also sometimes difficult to identify in the camera views. Any problems due to resolution were compounded by night time hours (in which visibility is lower) and sunlight glare (which "washes out" the camera). These aspects also made eye glance reduction much more difficult, although still possible in most cases.

While technological advancements in video have already overcome many of these problems, it is recommended that the usefulness of all five video channels be addressed prior to a large-scale study and trade-offs between video resolution and additional channels of video should be weighed carefully.

9.3 Analysis considerations

The following considerations are important in the analysis phase of an ND study:

- Definitions of start and end of a trip have to be established
- Routines for data quality check have to be an integrated part of any analysis
- A taxonomy of accidents and incidents must be developed, based on the recorded measures. Discrete events to be investigated have to be defined.
- A taxonomy of behaviour must be developed, with operational definitions of essential concepts like inattention, distraction, fatigue, sleepiness, etc.

- Possibilities of semi-automated analysis of video recordings should be investigated, to make the analyses less time-consuming.
- Appropriate methods of statistical analysis should be applied (see PROLOGUE Deliverable D2.2 for more details)

9.4 Database access management

It has to be decided where the database should be stored and who should be responsible for managing the database. Further, criteria for using the database for analyses must be defined. Should the database be open to any interested user, or should there be access restrictions? As the database will most likely contain proprietary and/or confidential information, it will be necessary to establish procedures for permission to access the information in question.

9.5 Data enrichment by complementary measures

For many research topics it is important to analyse relationships between the data recorded during driving and various other data not available in the primary database. Such variables may comprise, for example, background factors related to the driver, vehicle, environment, traffic conditions or road infrastructure. Such data may be derived by different methods, such as driver questionnaires and tests, road and vehicle registers, geographical information systems, etc. Some additional data may be location dependent, e.g. road geometry and road environment parameters, and may be linked to the primary database by means of GPS coordinates. Others may be both location and time dependent, e.g. traffic flow, and may be linked by both time codes and GPS coordinates.

Some relevant complementary measures are listed below, in various groups. An extensive list of measures is found in PROLOGUE deliverable D2.2 (Groenewoud et al., 2010).

9.5.1 Driver variables

Driver variables that can be added to the database include both *demographic measures* and *physical and psychological measures.* The most important demographic measures to be added are age, gender and driving experience. Other interesting measures are education, country of living, occupation (e.g. being a professional driver), and income.

The physical measures may include weight and height, and various health-related variables. A long range of psychological measures are interesting, as possible predictors of safety and environmentally related behaviour in traffic. Aggression, cognitive skills, risk perception, masculinity/femininity, sensation seeking, self-reported driving behaviour (e.g. the Driver Behaviour Questionnaire), and various measures of attitudes and intentions regarding driving as related to safety and environment.

9.5.2 Vehicle variables

Several research questions are related to the importance of vehicle characteristics and vehicle equipment for driving behaviour. Therefore it is important to add available vehicle information, e.g. from vehicle registers and vehicle manufacturers, to the database. Obvious and easily available information is vehicle type (make, model, year, etc.). The presence of various ADAS and IVIS systems is also important, in addition to information about type of transmission (manual/automatic) and energy system (diesel/petrol/electrical/hybrid).

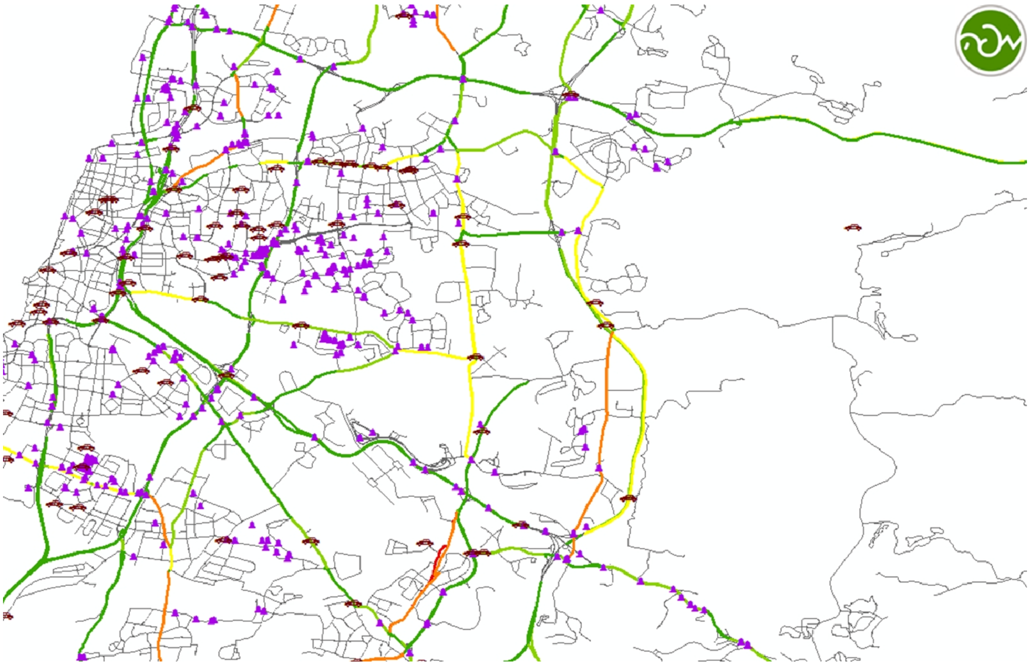
9.5.3 Environment, infrastructure and traffic variables

There is an almost endless list of possible measures to add regarding the driving environment. Such variables can be linked to the database by time code and/or GPS coordinates.

Combining ND observation data with a geographical information system was demonstrated in the PROLOGUE field trial in Israel (Lotan et al., 2010). In this subproject GPS coordinates of events (defined by *g* force sensors) occurring among novice drivers were linked to a digital map of the road network, containing various layers of information, like exposure, crash history, road characteristics, etc. Two examples illustrating the map-matching approach used in this project are shown in Figure 9.1 on the next page.

Some important categories of measures are traffic volume, road geometry (gradient, curvature, road and lane width, number of lanes, etc.), speed limit, signs and markings, and weather and road surface conditions.

It should be noted that some of these measures alternatively can be captured directly from the ND recording, e.g. from the forward-looking camera. Therefore there is some overlap between variables listed here and the directly recorded measures mentioned in Chapter 6.



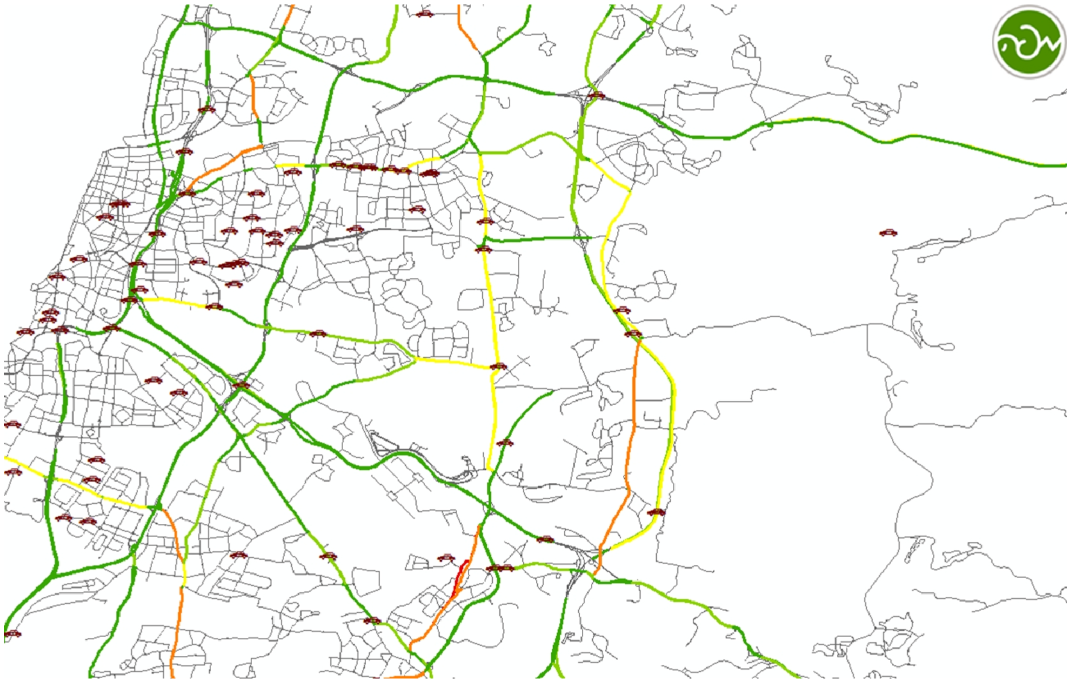


Figure 9.1 Example output from map-matching tool (ARCGIS Software) used in PROLOGUE field trial (Lotan et al., 2010). In-vehicle recordings of a particular type of incident ("braking while exiting a turn") shown as purple symbols are superimposed on a map with two additional layers: 1) road links with colour codes representing frequency of "severe events" with young drivers, and 2) accident locations (car icons).

Part 4: Towards a European large-scale Naturalistic Driving study

10 Key parameters for setting up an ND study

The two key parameters for designing an ND study are the *scale of the study* and the *sophistication of the technology* used for the observation.

10.1 Scale of the study

The scale of the study is largely determined by the size of the sample and the duration of the observation period as described above. Roughly three categories can be distinguished: small-scale, medium scale and large-scale. A *small-scale* study could involve the observation of up to e.g. 60 vehicle months (= about 5 vehicle years). This could be for example 60 vehicles being observed for 1 month, or 30 vehicles for 2 months, but also 10 vehicles being observed for 6 months. A *large-scale* study could involve observation of over e.g. 500 vehicle years. This could be 500 or more vehicles for 1 year or more. But it could also be 100 vehicles for 5 years or 6.000 vehicles for one month. A study with a scale between about 5 and 500 vehicle years would then be considered as a *medium scale* study. See Table 10.1 for an illustration of different combinations of sample size and study duration

The size of the study has large consequences for the organisation of the study and the potential research questions to answer. A larger scale study involves more organisational efforts, more finances and more issues to deal with than a smaller scale study. Not all topics require such a large-scale study. There is a huge potential for research questions to be answered by small or medium scale studies. However, some research questions do require a larger scale study. A large-scale is needed to study research questions related to rare events (e.g. crashes, specific distractions, etc.) or research questions that require representative samples (e.g. exposure to risk, monitoring, etc.).

Table 10.1; Scale of the study based on sample size and duration of observation

Sample size	Duration of observation		
	Short < 0.1 year	Medium	Long > 1 year
Small < 50 vehicles	< 50 vehicle months SMALL-SCALE		
Medium			
Large > 500 vehicles			> 500 vehicle years LARGE-SCALE

10.2 Sophistication of technology

Also the level of sophistication of the technology used for observation has large consequences for the organisation of the study and the potential research questions to answer. Not all topics require the most sophisticated measures. Many research questions could be answered using the simplest device only recording the basic parameters. This could be as simple as installing an App on a Smartphone. This is relatively low cost and provides a very interesting dataset. More sophisticated technology allows taking more measures. Some research questions do require such additional measures. Event triggered video could be used to explain and better understand the specific triggered situation. Video in general is considered a very rich source for explaining and understanding the non-video data. To study certain behaviours, such as distraction, video recording is required to observe what is actually happening in and around the vehicle. On top of the video, some research questions require additional specific measures, such as the measurement of eye movements by an eye tracker. Some research questions could require other specific measures like radar or emissions.

10.3 Scale of the study and sophistication of technology in relation to research topics

Looking at the research application areas discussed before, some of them have natural consequences for the potential study design in terms of the scale of the study or the observation equipment needed. For example, studying exposure would always require a large-scale study in order to acquire representative results. On the other hand, for studying speed and acceleration, observation equipment that measures only basic parameters would be sufficient, whereas to study distraction and inattention video would be needed and sometimes even specific additional measures like eye trackers.

The relationships between research topics and study design are not necessarily one-to-one. Different options are still possible dependent on the specific research question. For example, to study distraction and inattention does not necessarily have consequences for the scale of the study. Meaningful studies are possible with small-scale, as well as medium and large-scale studies.

Table 10.2; Mapping of study designs based on the key parameters study scale and observation equipment

Sophistication of observation equipment	Study scale		
	Small (<5 vehicle years)	Medium	Large (>500 vehicle years)
Specific additional measures	Distraction and inattention Fatigue, sleepiness and other acute impairments in normal driving		Distraction and inattention in relation to accidents
Video (Continuous or event triggered)			
Basic parameters	Speed and acceleration		Exposure

In Table 10.2 the two parameters *scale of the study* and the *sophistication of the technology* used for the observation are integrated into a framework. This framework roughly defines nine different study designs, being: small-scale/ basic parameters, medium scale/ basic parameters, large-scale/ basic parameters, small-scale/ event triggered video, etc.

When setting up a new study, the research questions should guide the choices for the scale of the study and the sophistication of the observation equipment. A group of research questions could be investigated based on a small-scale study measuring basic measures only. This could be for example a study on speed behaviour, comparing different age groups (25 novice drivers, 25 experienced drivers and 25 older drivers) driving in the same area for about 1 month. Some research questions require a larger scale study, e.g. when the object of study is rarer. Some specific behaviours (like distraction) require specific measures (like eye tracking). If one wants to investigate one particular distraction that is considered to be only a rare event, this would require advanced technology and a large sample. There are many options in between. A large-scale monitoring study, as being prepared in WP6 of the DaCoTA project (Talbot et al., 2010) typically fits in the lower right boxes: a large-scale study collecting basic parameters. The European project INTERACTION (*http://interaction-fp7.eu/index.php*), that investigates the use and misuse of in-car technology, is a typical example of a medium scale study with medium level observation equipment. To study the use of in-car technology continuous video recording is required, but no specific additional measures. The medium scale allows studying subgroups (different countries) and comparing behaviour between these groups.

Altogether there is a huge potential for ND research. When setting up a new study the challenge is to set the study parameters needed to meet its objectives. When working towards a new study, it would be helpful to list the research questions or topics towards the key parameters for study design, as was shown in Table 4.1. Such an overview provides insight to make choices on the study design and the potential of the study.

10.4 Cost considerations

The costs of a naturalistic driving study depend on many different factors. However, based on the two key parameters of the study design, the *scale of the study* and the *sophistication of the technology* used for the observation, it is possible to make some general statements. Roughly speaking, the costs increase when the scale increases and when the observation equipment becomes more sophisticated. This is illustrated in Table 10.4 by the arrow.

To provide a feel for the costs involved in the data collection in relation to the different study designs, Table 10.4 provides a very rough cost indication for some different study designs. This estimation is based on assumptions for the costs of each type of technology and the costs related to the different scales (sample sizes and duration). One has to realise that these costs are highly dependent on the DAS type chosen and that these costs have a strong tendency to decrease with improvements in technology. This cost estimation concerns costs for equipment and data collection and does not yet include other costs like data reduction and analysis costs. For the purpose of total cost estimation we have made the assumptions shown in Table 10.3.

If one wants to investigate crashes, a very large sample size is needed as crashes are quite rare events. If a specific crash type is investigated, this event is even rarer and a larger sample is required to collect enough cases. How rare is this event? What sample size would be required? What does this mean for the costs in case of the different levels of technology?

Table 10.3; Assumed unit cost assumptions for estimating total data collection costs (Euros)

Sophistication of observation equipment	Equipment and installation costs per vehicle	Data collection costs per vehicle year[7]
Basic driving parameters	300	1500
Additional video	2000	2500
Specific additional measures (e.g. eye-tracking)	4000[8]	4000

A large-scale study with the most sophisticated observation equipment would provide certainly the richest dataset but at the same time would be the most costly. One way to optimise costs and maximize the richness of the data would be to compose a sample existing of vehicles equipped with different kinds of observation equipment. A large-scale sample would be equipped with basic observation equipment. Out of this sample, a medium scale sample will get additional equipment for video observation. Out of this medium sample, a small-scale sample will be equipped with the most sophisticated equipment to take some specific additional measures. This is illustrated by the blue cells in Table 10.4.

Table 10.4; Indication of costs for data collection in relation to the study design.

	Study scale		
Sophistication of observation equipment	Small (<5 vehicle years) *e.g. 25 vehicles* *for 2 months* *(4 vy)*	Medium *e.g. 100 vehicles* *for 2 years* *(200 vy)*	Large (>500 vehicle years) *e.g. 1000 vehicles* *for 2 years* *(2000 vy)*
Specific additional measures	116 K	1 200 K	12 000 K
Video Continuous or event triggered	60 K	700 K	7 000 K
Basic parameters	13,5 K	330 K	3 300 K

[7] This amount includes a participant monetary compensation arbitrarily estimated at 500 per year. Reported problems to recruite sufficient numbers of participants in SHRP2 study may imply that higher participant incentive is needed.

[8] For comparison, the unit cost of the SHRP2 DAS is about $4000. Without the forward radar (which is the most expensive part) it is about 2100.

This sample configuration allows benefiting from the advantage of the large-scale together with the advantages of the sophisticated observation equipment for a minimum of costs. This research design would be cost effective and very rich, as there is a possibility to generalise results from the small-scale sample to the large-scale sample based on the basic driving parameters. Also the small-scale sample could be used to explain or understand cases from the large-scale sample. However, this design doesn't cover all the boxes, so a number of research questions that require large-scale and sophisticated observations could not be studied by this study design.

11 Synthesis

11.1 The European situation

The 100-car study in the U.S. was a major breakthrough for road safety research worldwide. It showed that it was actually possible to observe drivers in their day-to-day behaviour and thus get unique information on, for example, distraction and inattention. For the U.S. this paved the way for the SHRP2 large-scale ND study that intends to create a database of driver behaviours suitable for very many interesting a priori and post hoc analyses. In Europe ND observations have been and are included in field operational tests (FOTs) in which specific systems (usually in-car ITS) are evaluated on a large scale.

PROLOGUE has shown that the European situation for a large-scale ND study is different from the U.S. and different from FOTs. The information from the literature, questionnaires, pilot studies and workshops indicates that a large-scale ND study is preferably a combination of research dedicated to specific topics (distraction, risks, performance indicators, etc.) as well as a general database. It also shows that this is focused on, but not limited to safety. Eco-driving and traffic management are considered vital extensions.

The exact reasons for these differences are unclear. However, an educated guess would probably consider:

- the EU lacking a TRB (Transportation Research Board) that is capable to advocate, organise and realise funds for large-scale research;
- the EU vision to use R&D in strengthening European competitiveness of the private sector, resulting in e.g. FOTs;
- the successes of European road safety policy (EU, member states, citizens, industry, …) in the last decade, almost halving fatality rates and clearly different from the U.S.;
- growing attention to the ‘greening' of road transport.

None of these are likely or even desirable to change; it seems that the European situation will be stable in the near future.

11.2 Stakeholders' interests and research topics

From literature, user forum questionnaires and the workshops, PROLOGUE shows that many stakeholder groups are interested in the outcomes of a large-scale ND study. The main stakeholder groups identified are (linked to) insurance companies, the automotive (supplying) sector and policy makers (incl. licensing, road authorities, enforcement etc.). The most important research topics are linked to general behaviour (driving style, performance, …), exceptional behaviour (impairment, inattention, …), events ((near) crashes, harsh braking etc.). Combining these categories to conditions regarding the driver background, road design, traffic, vehicle type etc. defines a matrix in which the subsequent cells form a class of research questions. For instance: Where do young/experienced drivers speed? Which in-car systems lead to distraction? Etc.

The data gathered in PROLOGUE is too limited and biased to allow for an evidence based combination of stakeholders and topics. The nature of the stakeholder group, however, allows for educated guesses of these combinations. The automotive sector is undoubtedly mainly interested in the condition ‘vehicle' and likely to be interested in relevant topics such as (rare) events and (near) crashes, driving performance and eco-driving. For insurance companies the focus will be on the driver, possibly in combination with the vehicle, but probably less so in relation to the infrastructure, though providing incentives to avoid high risk routes might be an issue. For road authorities speeding or the occurrence of events in relation to road design seems interesting, etc.

11.3 Methodological aspects and data issues

The research questions determine which parameters need to be measured and which sample (size, specific groups) is appropriate. For the non-safety topics (eco-driving, traffic management) basic parameters on e.g. exposure, routes or speed (change) are sufficient, for many safety related topics (inattention, crash avoidance) video observation and/or eye-tracking is vital.

Much added value (see Section 1.5) is in the detection of rare events. The order of magnitude for fatal or severe (KSI) crash rates is 1-10 per 10.000 road users per year. This implies that acquiring a representative sample of KSI crashes would take a sample size of millions using the most sophisticated data acquisition systems (DAS). This is clearly not feasible. The focus should therefore be on less severe crashes, near crashes and other risk-related events. There is need for cooperation across continents, for example with the U.S., Australia or Japan to increase (comparable) sample sizes and discuss the definition of events and near crashes and their relation to KSI crashes. There is also need to enrich the ND data with information from other (traditional) research such as analysis of police records, in-depth studies, questionnaires, simulators, etc. A third way to go is to include parameters relevant for monitoring safety performance indicators (SPIs) which were and are under study in EU projects SafetyNet and DaCoTA. In fact there is a liaison between PROLOGUE and DaCoTA WP6 on SPIs.

Specific attention should be given to vulnerable road users (VRUs), especially two-wheelers (powered or bicycle) and pedestrians. The DAS should be able to detect these from the ND vehicle (car, HGV), e.g. by using outwardly directed cameras and sensors. An alternative would be to equip the two-wheeler itself, which is done in the EU project 2BSAFE. For bicycles and pedestrians, a site-based study, possibly combined with in-car studies would be recommended, though equipping the VRU itself with, for instance with a smartphone, is tempting.

Much added value is in creating a large database for analysing (near) crash data and allowing for cross-country comparisons (see Section 1.5). A major risk to this approach could lie in privacy, liability and legal issues. This appeared to be an important issue in the SHRP2 study as well as in, for example, EuroFOT and in-depth EU projects like PENDANT (*http://www.vsi.tugraz.at/pendant/*). However, large-scale European FOTs like EuroFOT or AOS (*http://www.fileproof.nl/aos/index.html*) showed that using informed consent, insurance etc. This can be tackled at a national level. Furthermore it can be resolved by avoiding detailed vehicle (CAN-bus) data and by setting up a centralised database that can be approached via a secure internet connection.

11.4 An aid for making a study design

These above-mentioned observations lead to the conclusion that a feasible scale European ND study is probably a combination of large samples using basic DAS, medium size samples using event triggered video and small-scale samples using site-based cameras and continuous video, possibly including eye-tracking. All of these are highly dependent on available budgets.

In order to formulate a study, the “ND chain” of Section 1.4.2 might be helpful; this is an approach that is similar to the setting up of a FOT according to the FESTA handbook (the "V"). Some initial steps that differ between FOT and ND are highlighted in Figure 11.1.

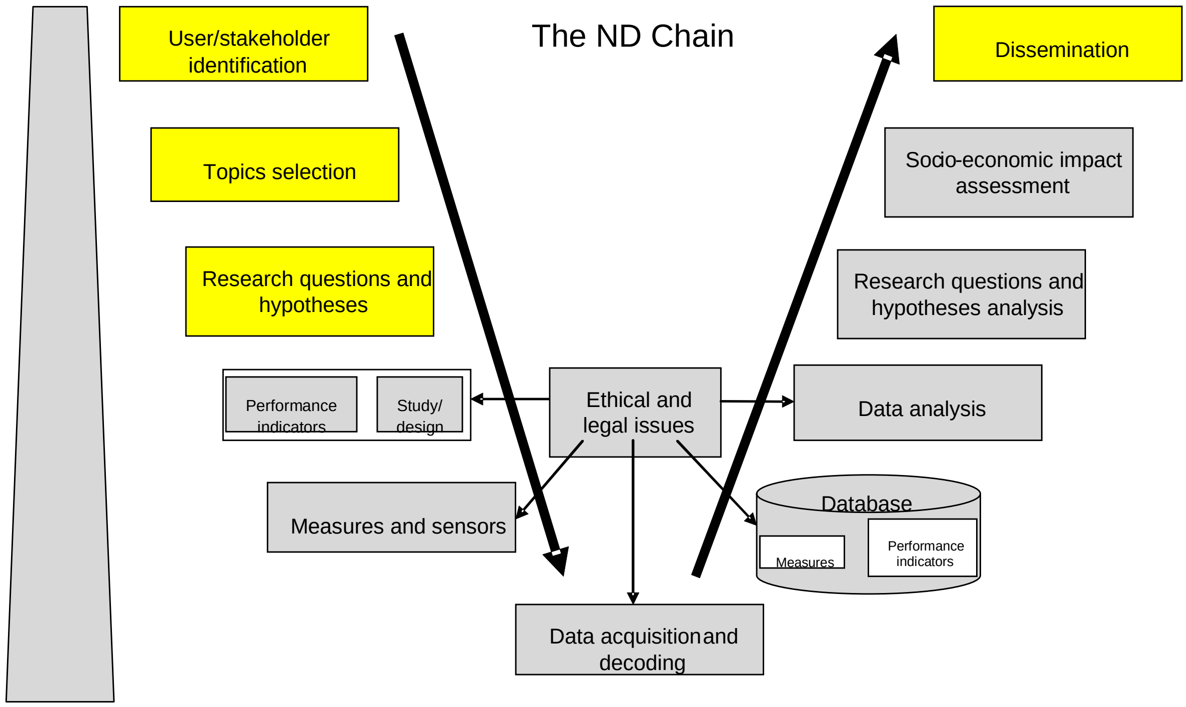


Figure 11.1 The FESTA "V" (FESTA Consortium, 2008) adapted to ND studies, with differences highlighted (in yellow).

Making the best choice of study methodology means bringing together stakeholder interests, research topics, and constraints such as available technologies and budgets. In the previous Chapter, Tables 10.2 and 10.4 show how research topics and technologies are linked and which costs might be expected. In Table 11.1 an attempt is made to bring these three items together; this might be helpful for different scales of study.

Step 1: Stakeholder identification and involvement: As shown many stakeholders and user groups are interested in the outcome of ND studies, but not (necessarily) to the same extent and with different aims. In Table 11.1 rather general examples are given, whereas e.g. a supplier of navigation or safety systems has more limited and different interests than an OEM. It is important here that a rough estimate of budgets is available.

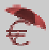
Step 2: Topics selection: This is linked to the identified stakeholders but should be expressed by the individual stakeholders and/or founders. Again, the topics in Table 11.1 serve only as examples; in Chapter 2 a more comprehensive overview is given from which the topics can be selected.

Step 3: Research Questions: here the "behaviour X conditions" matrix (Section 2.3.3) is helpful to specify what the interest of each stakeholder is, for example in a basic study on general driving performance.

At the end of step 3 stakeholders can place their icon in the cells of their interest and depending on the outcome, discuss the nature and size of the basic, trigger-based, continuous and/or specific study elements. This will result in a preliminary set-up, probably followed by several iterations before a final choice is made. Also the subsequent steps (performance indicators, study design etc.) may initiate an extra iteration. Once the data acquisition is running and the progress is made up the slope of the "V", the iterative process must be finished.

In case the stakeholder groups are various and there is an external financer such as the EU, the initial steps are in principle alike but in practise less limiting. It is, however, important to involve them closely. The final step 'dissemination' will be more important than in case of clear (individual) paying stakeholders. Organising workshops, questionnaires, advisory bodies etc. might prove valuable at both ends of the "V".

Table 11.1 Illustration of an aid for setting up the study design.

Topics	Basic	Trigger based	Continuous	Specific additions	Remarks
Exposure & risk				 	Site-based VRU
Fatigue, inattention					
General driving performance					
Road system					
Eco issues					
Traffic management					

 = insurance companies

 = automotive industry

 = policy makers

 = research institutes

11.5 Summary of recommendations

The recommendations presented in this report are on different levels regarding degree of specification. Some of the recommendations are rather specific, whereas most are general. We have deliberately refrained from very detailed specifications regarding e.g. choice of equipment. This is because technological development is very fast, and recommendations may therefore soon become outdated. It should therefore be left to the future projects to make the detailed specifications. Also the research questions have been phrased more like global topics rather than specific questions and hypotheses.

The matrix of research topics is supposed to be a tool for future research project in the process of formulating specific research hypotheses.

The most important general recommendations for a large-scale European naturalistic driving study can be summarized in 11 items, as follows:

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.

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List of Abbreviations

ADAS:	Advanced Driver Assistance System
CAN:	Controller Area Network
DAS:	Data Acquisition System
DBQ:	Driver Behaviour Questionnaire
DRL:	Daytime Running Light
ESC:	Electronic Stability Control
EDR:	Event Data Recorder
FOT:	Field Operational Test
GPRS:	General Packet Radio Service
GIS:	Geographical Information System
GPS:	Global Positioning System
HMI:	Human Machine Interface
IVIS:	Intelligent Vehicle Information System
KSI:	Killed or Severely Injured
ND:	Naturalistic Driving
OOPO:	Out-Of-Position Occupant
PAR:	Population Attributable Risk
PDO:	Property Damage Only
PTW:	Powered Two-Wheelers
rpm:	revolutions per minute
SDLP:	Standard Deviation of Lateral Position
SHRP2:	Strategic Highway Research Program 2
SPI:	Safety Performance Indicator
SQL:	Structured Query Language

Appendix I: Environmental relevance of naturalistic driving

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Environmental relevance of ND

Richard Smokers, TNO

draft v1.0 - 13/02/2011
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Introduction

This paper illustrates the influence of driving behaviour on real-world vehicle emissions and fuel consumption, and motivates why and how experiments with ND are relevant for increasing our knowledge on ways to reduce the environmental impact of traffic by means of influencing driving behaviour. In the short term this knowledge can be used to design effective measures for improving air quality in urban areas. In the longer term more detailed knowledge of the relation between driver behaviour and vehicle energy efficiency is relevant for the optimal design of efficient vehicles and in-car driver feedback instruments as well as of advanced traffic management systems and other ITS applications that will help to reduce CO_2 emissions from transport in a cost effective manner.

Driver behaviour is an important determinant of vehicle emissions and fuel consumption

Fuel consumption and emissions of road vehicles are determined by three major factors:

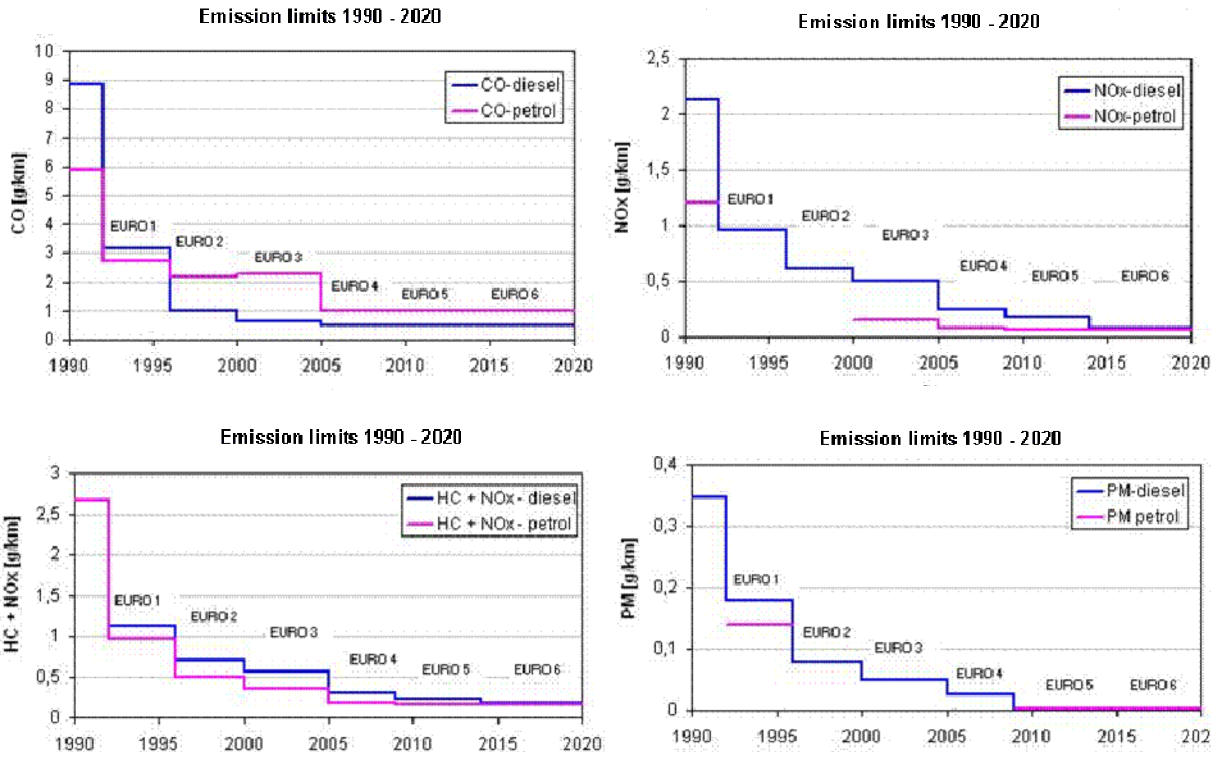
- Technical aspects of the vehicle
  - engine technology and exhaust aftertreatment
  - vehicle mass, rolling resistance and aerodynamics
- Traffic circumstances
  - road type
  - maximum speed
  - level of congestion
- Driver behaviour
  - driving style
  - use of (energy consuming) accessories

These three factors can also be used to limit fuel consumption and emissions. In the case of technology this is done mainly through emission legislation (e.g. Euro standards and CO_2 legislation). Traffic circumstances are influence by road design, and on existing roads can be changed by means of traffic management measures. Driving behaviour is e.g. influenced by campaigns or lessons promoting the application of an energy efficient driving style. Behavioural changes can be supported or further enhanced by using in-car fuel consumption feedback instruments.

With vehicles becoming cleaner on the type approval test the influence of driver behaviour on real-world emissions has increased

Figure 1 shows the evolution over the past decades of the emission limits for passenger cars in Europe. It can be seen that especially petrol vehicles have become a lot cleaner since 1990. This is mainly due to the application of the three-way catalyst. Until recently for diesel engine no such aftertreatment technology was available. For that reason Euro 1 – Euro 4 emission limits for diesels have been higher than those for petrol vehicles. More recently, however, aftertreatment technologies have become available for diesel vehicles. These include particulate filters, NO_x-storage catalysts and SCR-deNOx systems. Starting with Euro 5 the emission limits for diesels have been progressively reduced. With Euro 6 they will become quite comparable with those for petrol vehicles.

Figure 1 Evolution of emission limits for passenger cars on petrol and diesel in Europe (source TNO)



Emission standards relate to a prescribed standardised driving cycle (speed-time pattern) that is used to test the vehicle in the laboratory on a chassis dynamometer. Especially in Europe and Japan, and to a lesser extent in the U.S., this driving cycle is not accurately representing real world driving behaviour. The European and Japanese type approval driving cycles are synthesized from straight line elements and display significantly lower accelerations that real-world driving patterns and especially significantly less dynamics (speed variations). The performance of exhaust aftertreatment systems is governed by control systems that have a finite response time to variation. Under static or slowly varying load conditions emission reduction rates are high, but under transient conditions emission peaks may occur when the control system is not able to accurately follow the load dynamics. This effect can be clearly seen from the comparison of Figure 2, with NO_x emissions of a modern petrol car recorded on the New European Driving Cycle prescribed for type approval testing, and Figure 3, depicting NO_x emissions of the same care recorded on the Common Artemis Driving Cycle, which has been derived from recorded real-world driving patterns. In modern petrol vehicle NO_x emissions are close to zero under static or slowly varying load conditions in the NEDC-cycle, but the more dynamic load changes occuring in the CADC-cycle NOx peaks can be observed which make up the majority of the NO_x emissions measured over the entire cycle.

For diesel vehicles the mechanism underlying the difference between type approval and real-world emissions is different. Deviations are not so much related to delay times in the exhaust aftertreatment control system, but are more generally caused by differences in engine loads and the impact of transients on engine-out emissions. This is illustrated in Figure 4. With the advent of more complex, electronically controlled aftertreatment technology in Euro 5 and Euro 6 diesel vehicles it is likely that similar effects as with petrol cars will also occur in diesels.

Figure 2 Example of an emission measurement over the NEDC-cycle (with cold start) showing recorded speed and measured NO_x emissions for a petrol vehicle (source TNO)

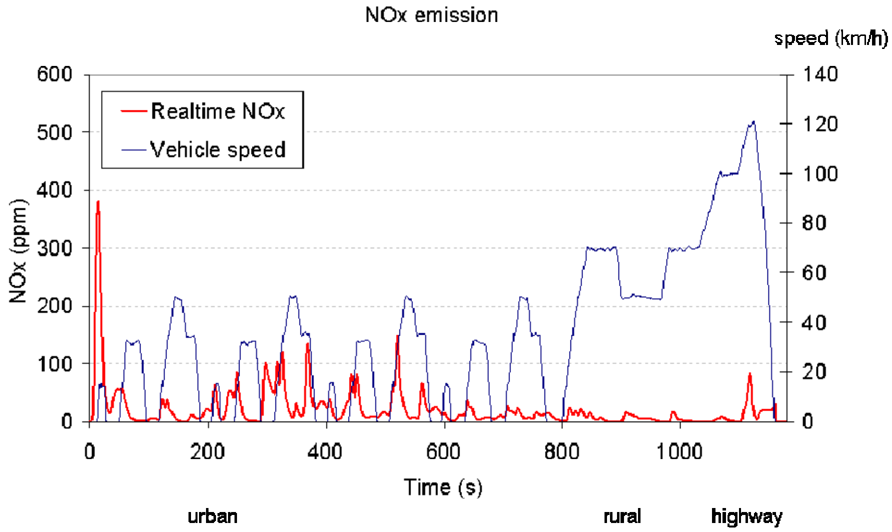
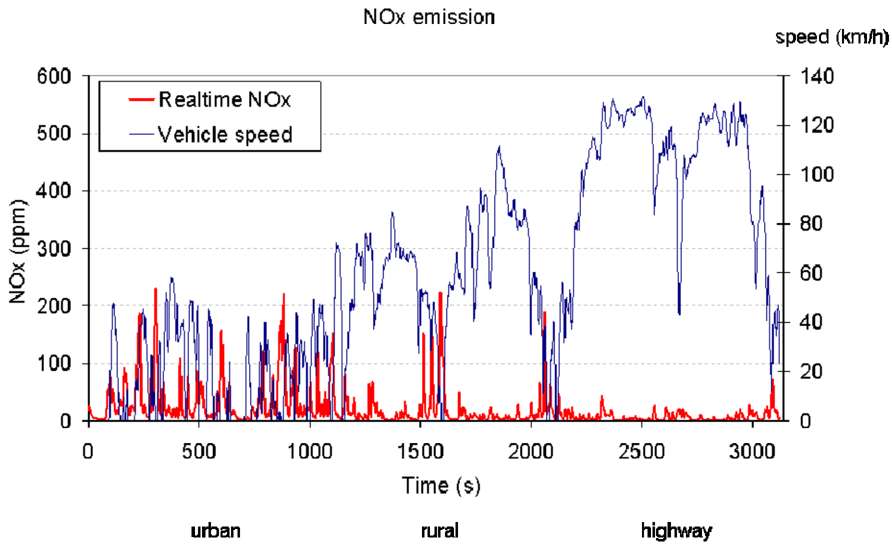


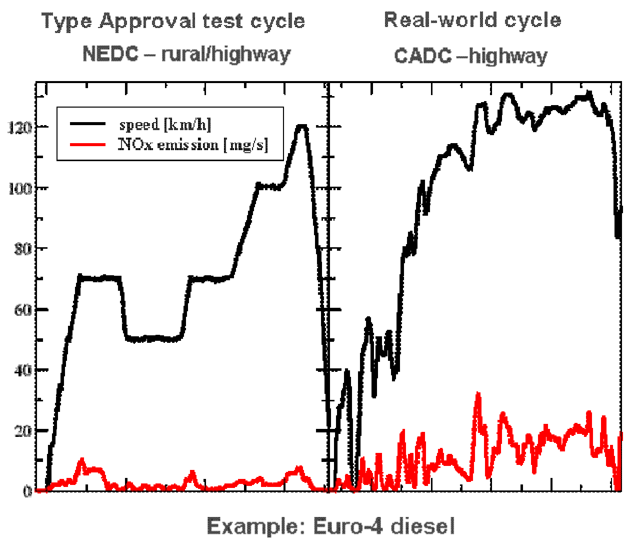
Figure 3 Example of an emission measurement over the real-world derived CADC-cycle (with hot start) showing recorded speed and measured NO_x emissions for a petrol vehicle (source TNO)



One result of the above-described effects is that real-world emissions of cars in g/km have not decreased with the same rate as the emissions measured on the type approval test. Together with a higher than expected growth in traffic volumes this is the reason why many cities in Europe are not able to meet the EU air quality standards in time.

The influence of driving dynamics, as shown from the comparison between emission measurements on the NEDC and CADC cycles, also explains why driving behaviour can strongly influence emission. Given certain road conditions and traffic intensity, which determine the extent to which driving patterns are "traffic forced", the driver's right foot still has a strong influence on the engine loads, through the aggressiveness of the driving style, and on the "small-scale" dynamics in the speed-time pattern.

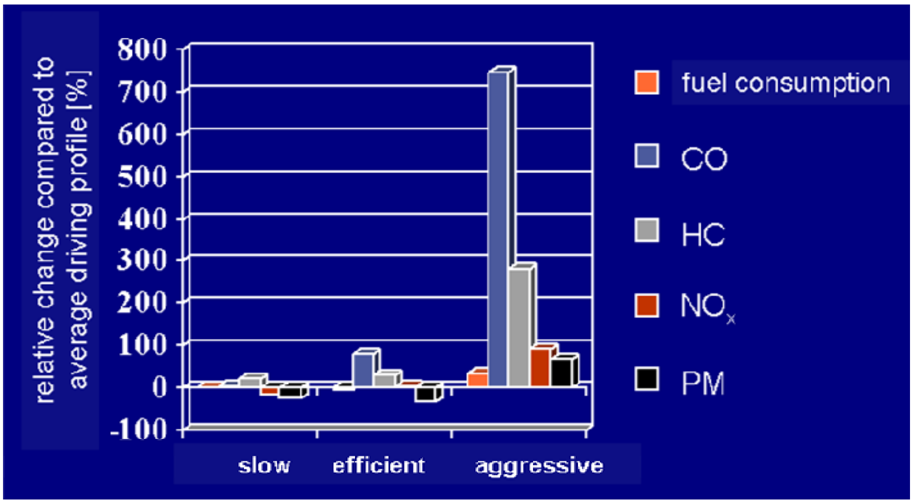
Figure 4 Comparison of NO_x emission measurements over the standard NEDC-cycle and the real-world derived CADC-cycle for a Euro 4 diesel vehicle (source TNO)



Aggressive driving styles increase fuel consumption but especially increase emissions of air pollutants

The influence of driving style on fuel consumption and exhaust emissions is illustrated in Figure 5, which is based on chassis dynamometer measurements on a range of vehicles using driving cycles derived from recorded real-world profile. Impacts are expressed relative to the emissions occurring on a driving cycle that represents more average driving behaviour. As can be seen aggressive driving can increase exhaust emissions by a factor or more.

Figure 5 Influence of three specific driving styles on fuel consumption and emissions relative to "average" driving behaviour (source TNO)

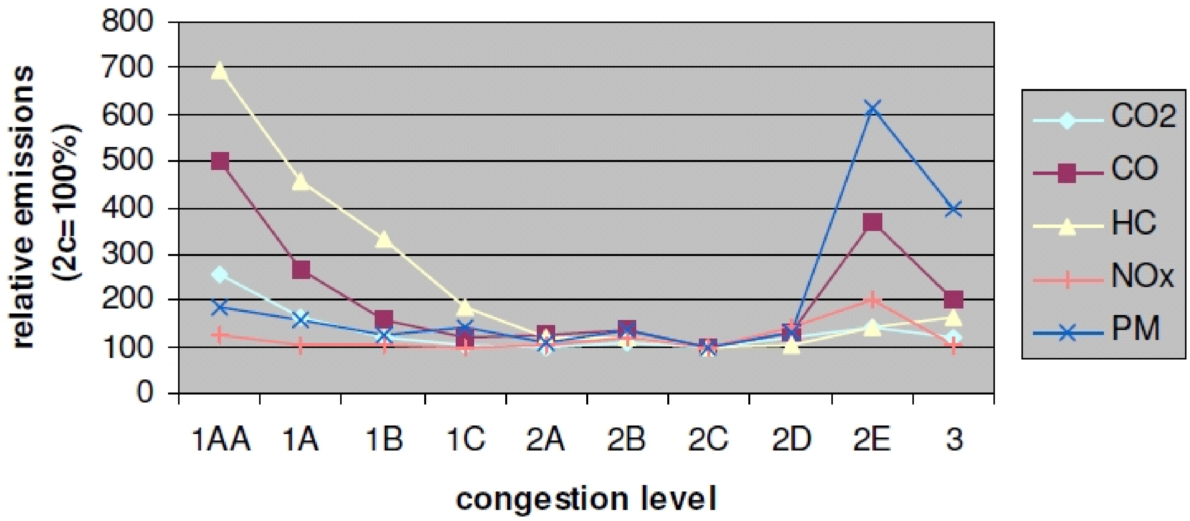


An important issue for determining the impact of aggressive driving styles on overall emissions of traffic is the share of aggressive driving. This is determined by the share of aggressive drivers in the overall driver population, their share in the overall mileage, the age of the vehicles that they drive, and the amount of time that these drivers are able to "act out" their aggressive driving style given the influence of road and traffic conditions on driving. It is especially on this issue that ND experiments can generate extremely useful information.

Traffic management measures may reduce emissions and congestion but need to be carefully implemented

Figure 6 shows the impact of various levels of congestion on the fleet average emissions of passenger cars. Severe congestion results in stop-and-go traffic which in turn leads to emissions which are up to a factor 7 higher than under less congested conditions with average speeds between 75 and 120 km/h. Under "free flow" conditions a significant part of the drivers will drive faster than the allowed speed limit, which also leads to strongly increased emissions. This knowledge inspired the application of traffic management measures in which enforcing a reduced maximum speed is used to improve air quality near highways in urban areas. A well enforced reduction of the maximum speed not only leads to lower emissions due to the lower speeds, but also leads to reduced dynamics (speed variations and speed differences between vehicles). This in turn reduces the formation of traffic jams, which also avoids situations of high emissions.

Figure 6 Fleet average vehicle emissions as function of the congestion level on highays (source TNO)



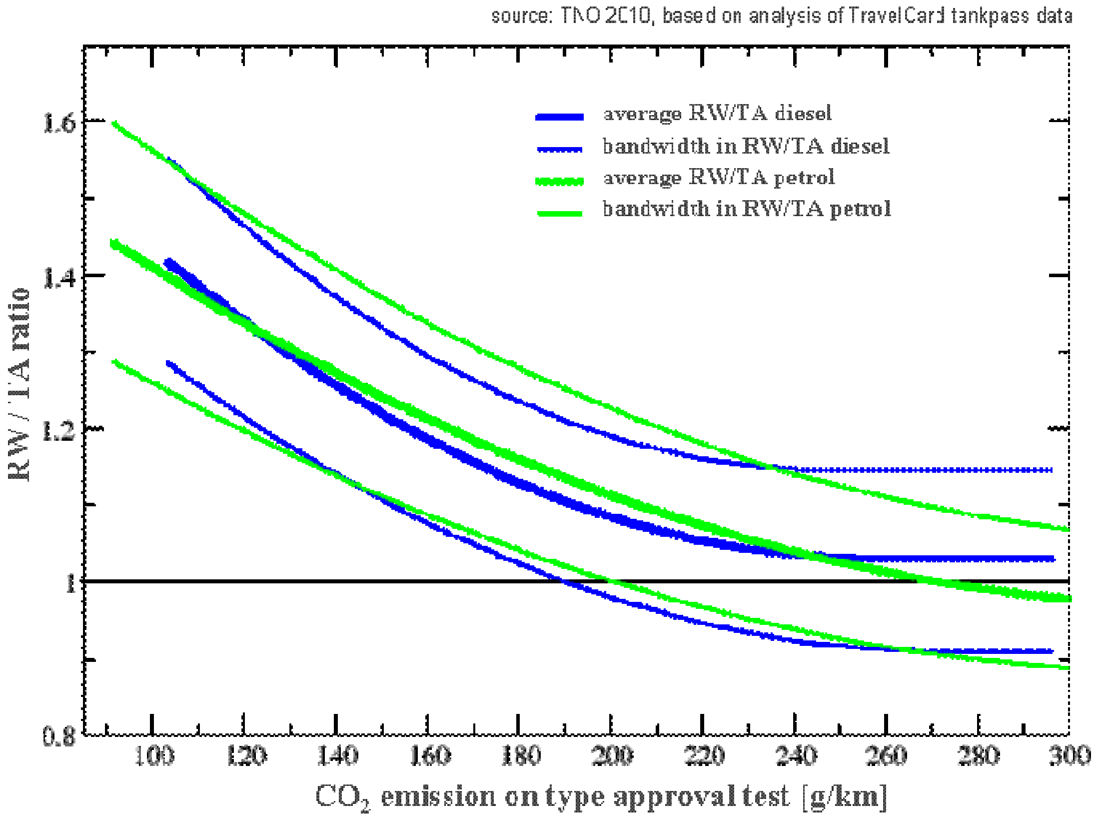
Congestion category	*Definition*
1aa	Speed <10 km/h; 'stop and go'
1ab	Speed between 10 and 25 km/h
1a	1aa and 1ab combined, speed between 0 en 25 km/h
1b	Speed between 25 and 40 km/h
1c	Speed between 40 and 75 km/h
2a	Speed 75-120 km/h, traffic volume over 1000 vehicles per lane per hour, speed limit = 100 km/h
2b	Speed 75-120 km/h, traffic volume over 1000 vehicles per lane per hour, speed limit = 120 km/h
2c	Speed 75-120 km/h, traffic volume below 1000 vehicles per lane per hour, speed limit = 100 km/h
2d	Speed 75-120 km/h, traffic volume below 1000 vehicles per lane per hour, speed limit
2e	Speed over 120 km/h, independent of traffic volume
3	Shortcut/back road

Application of this type of traffic management in the Netherlands has taught that the way in which such measures are implemented strongly influence the achieved impacts on congestion and air quality. Careful implementation, tailored to the local infrastructure and traffic characteristics, improves the reduction potential and avoids displacing problems with congestion and emissions to road sections connected to the area in which the measure is applied. An important ingredient of this careful implementation is the communication with the driver. ND experiments can provide useful information on how to implement traffic management measures in an optimal way maximizing local benefits without rebound effects on safety or congestion and emissions elsewhere.

The influence of driving styles may increase as a result of the introduction of technologies improving the fuel efficiency of cars

The combination of the EU CO_2 legislation for passenger cars and national tax incentives has led to an accelerated market uptake of fuel efficient cars in recent years. These vehicles include two main categories: relatively small vehicles (ref. Toyota Aygo), which have low fuel consumption due to their small mass and often also limited performance, and vehicles with advanced technologies which improve overall energy efficiency (ref. hybrid vehicles such as the Toyota Prius and efficient diesel vehicles such as the VW Polo BlueMotion). Both the legislation and tax incentives relate to CO_2 emissions as measured on the type approval test. For a long time it was already know that type approval CO_2 emission or fuel consumption values are on average between 15 and 20% lower than values observed under real-world driving conditions. A recent analysis of fuel consumption data of a large fleet of company cars, however, has shown that this difference appears to increase with increasing fuel efficiency of vehicles (see Figure 7).

Figure 7 Ratio between average real-world (RW) fuel consumption (or CO_2 emissions) and the value measured on the type approval (TA) test as a function of the CO_2 emission value measured on the TA test (source TNO)



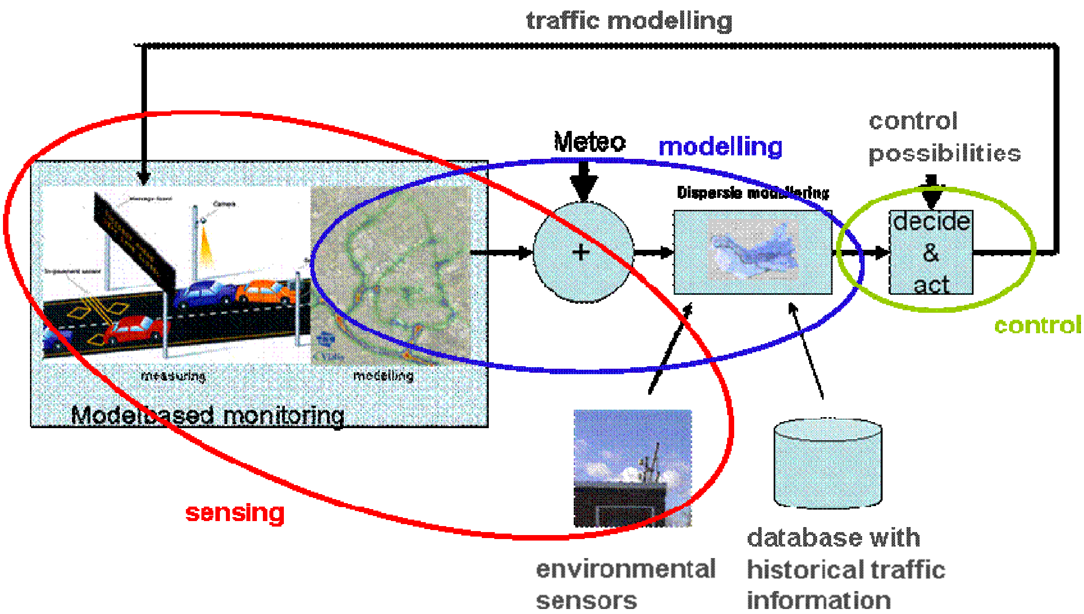
Technical measures to improve power train efficiency in general reduce the difference between peak efficiency and the efficiency under part load conditions. On the one hand this may reduce the impact of speed and driving dynamics on fuel consumption. But at the same time this may also increase the impact of aggressive driving. In a conventional vehicle aggressive driving leads to a higher energy requirement at the wheels, but due to the higher loads this energy is produced by the engine with an efficiency that is better than what would the case with a more moderate driving style and the resulting part-load operation of the engine. The higher efficiency at peak loads thus partly counteracts the higher energy demand at the wheels. In vehicles with a "flatter efficiency map" variations in the energy required at the wheel more directly translate into variations in fuel consumption.

This subject deserves further study, but the above indicates that a better understanding of the share of aggressive drivers and the impact of aggressive driving may be important for the successful introduction of advanced technologies to improve fuel consumption. Also here ND experiments may thus generate valuable information. The experiments may also be used to test in-car fuel economy feedback systems, generating insights that may lead to more effective designs of such systems.

ND experiments will generate useful insights for the optimal design of advanced traffic management systems

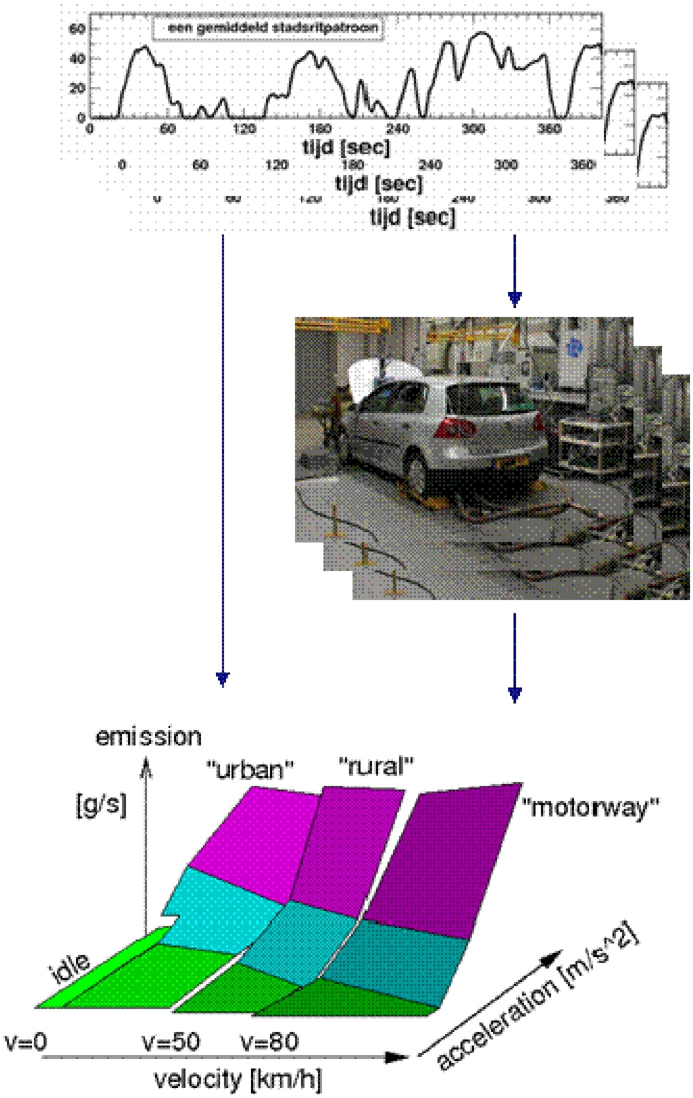
Recent advances in sensor technology and (real-time) modelling have led to the development of advanced traffic management tools that may be used to simultaneously improve traffic flow and reduce traffic emissions. The overall design is illustrated in Figure 8. Such systems are currently being tested. There effectiveness not only depends on technological innovations with respect to sensors and models, but also on appropriate means to influence drivers to implement the required changes in their driving patterns or route choice. Experience gained in ND experiments will be extremely useful for the design of appropriate "interfacings" between the traffic management system and the drivers. Furthermore these experiments can generate more detailed insight in the variation of driving styles and may thus help to better identify target groups for which behavioural changes have the highest impact on traffic flow and emissions.

Figure 8 Illustration of advance, measurement and model based traffic management systems (source TNO)



Advanced traffic management, that aims to not only improve traffic flow but also to reduce emissions, not only requires advanced road-side sensors, but also advanced emission factor modelling to assess the impact of changes in traffic flow, average speed and speed variations on real-world vehicle emission performance. TNO has developed the VERSIT+ model that is able to perform such a function. As indicated in Figure 9 it calculates emissions as a function of characteristics of speed-time profiles. The model is based on elaborate statistical analysis of chassis dynamometer measurements on a large number of vehicles submitted to a wide range of driving cycles derived from recorded real-world driving profiles.

Figure 9 Illustration of how the TNO VERSIT+ model can be used to generate emission factors for specific driving profiles (source TNO)



Requirements for the set-up of ND experiments from the point of view of generating environmentally relevant information

Including environmental aspects in large-scale experiments with ND may require changes in the set-up of the experiments. These changes may include additional recording of parameters related to driver behaviour or vehicle driving characteristics in a given experimental set-up or even changes in the situations to which drivers are exposed during the experiment.

Requirements with respect to vehicle driving characteristics include the recording of speed / time / location information and if possible also instantaneous fuel consumption (e.g. from the vehicle CAN-bus). Actual vehicle emissions are difficult to measure in real-time. Emission measurement, however, is not necessary as the impact of changes in driving style on emissions can be estimated using advanced off-line emission factor modelling.

It is expected that speed / time / location information will already be recorded for other purposes in most experiments with ND. Collection and statistical analysis of this information will already contribute considerably to the knowledge base that is necessary for assessing the influence of driving styles on environmental performance and for the correct design of advanced traffic management measures.

Changes in the recording of driver behaviour may relate to the response of drivers to information provided from the road side or by in-car instruments. Such measurements will generate insights that are crucial for the optimal design of measures such as in-car instruments, advanced traffic management and ITS that are intended to influence driving behaviour for the improvement of traffic flow and/or environmental impacts of traffic.

Appendix II: Information to potential SHRP2 study participants

Participant Information Sheet: The SHRP 2 ND Study

The ND Study is a large research effort directed at improving Highway Safety in the United States where more than 30,000 people are killed and 2 million are injured every year in highway-related accidents. The study will help researchers gain a deeper understanding of the interaction between the driver, vehicle and roadway and lead to safer roadways, vehicles, and driver training programs. The SHRP 2 ND Study will look at how people normally drive by installing cameras and sensors in people's own vehicles. The study is being conducted at six locations across the United States with up to 3,100 participants. About three-fourths of participants will be in the study for one year, and the rest for two years. About 340 participants will be minors.

If you decide to participate in the study, we will install several pieces of data collection equipment in your vehicle. The equipment will collect data continuously, from the time your vehicle is turned on until it is turned off. There will be video of your face, arms, and legs that will tell us what you do while you drive. There will also be video of the forward roadway and the roadway behind your vehicle. GPS will provide the location of the vehicle. Sensors will measure speed, braking, turn signal use and other vehicle and driver behaviours.

The risk while driving will be the same as the risk of driving when not in the study. Although there is only a low probability of occurrence, the biggest risk believed to be associated with participation in this study is the possibility that someone could obtain your data and use it in a way that harms you legally, financially, or emotionally. To prevent this, we have taken several steps to ensure your confidentiality and the confidentiality of your passengers and other people who drive your car.

A Certificate of Confidentiality has been obtained from the National Institutes of Health. With this Certificate, the researchers and study sponsors cannot be forced to disclose information that may identify you, even by a court subpoena, in any federal, state, or local civil, criminal, administrative, legislative, or other proceedings.

The data will be encrypted (made unreadable) from the time it is collected until it is transferred to a high security data center. Once it is at the data center, care will be taken that the data are only used for legitimate research purposes.

Data that can identify you, such as video of your face and the GPS locations of your home, work, or school, will be handled with extra care and will only be available to select researchers in a secure data center.

The data of other drivers who have not signed a consent form will be deleted after data processing identifies them as unconsented drivers. No identifying information will be collected on passengers.

If you decide to participate, you will be asked to do the following things:

- Provide us with proof of a valid U.S. driver's license, vehicle insurance, and vehicle ownership.
- Undergo a consent process which includes reviewing and signing an informed consent form.
- Allow us to install the data collection equipment in your vehicle.
- Undergo tests of vision, memory, decision making, attention, body movement, and strength.
- Complete questionnaires about your health and your driving behaviour, history, and knowledge.

If you are in a crash, we may ask you later to participate in an interview about the crash and allow us to look at the police accident report.

There is compensation for participation in the study at the rate of $300 per year.