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PROLOGUE

# A catalogue of applications and research topics for future naturalistic driving studies

## Deliverable D1.3


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# Abstract

The present report is the final deliverable from Workpackage 1 ("Identification of potential areas of application and research") of the project PROLOGUE within the EU 7th Framework Programme. The main objective of PROLOGUE is to demonstrate the usefulness, value, and feasibility of conducting a large-scale naturalistic driving observation study in a European context.

The report presents a framework for defining research topics and questions that are especially relevant and suitable for being investigated in such a study. The purpose of future research is supposed to be investigation of driver behaviour in relation to safety as well as to environmentally friendly driving and traffic management issues. A similar work being carried out within the US Strategic Highway Research Program 2 (SHRP2) is reviewed and is used as a source of reference for defining research topics. The research topics are defined in terms of combinations of: 1) categories of driving behaviour and driver states, and 2) conditions under which these behaviours may be observed. The matrix resulting from combining these two sets of categories is considered to be a useful framework for classifying and defining more specific research questions for future ND studies. The driver-related categories to be investigated include: distraction and inattention; fatigue, sleepiness and other 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 categories of conditions for which they should be studied, include: driver background factors and trip characteristics; road system, road environment, and ambient conditions; vehicle design, equipment, and condition; traffic volume and composition, interaction with other road users.

Traffic safety has been the main focus of most previous and ongoing ND research. However, the method is well suited also for investigations of traffic flow and environmentally friendly driving (eco-driving).

A user survey showed that "risk taking behaviour" and "crash avoidance behaviour" were the two topics that were considered (very) important by the largest number of respondents. In addition to the thematic research topics, there is a need for methodologically focussed ND studies, including validation of the ND approach itself.

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# Executive Summary

Naturalistic driving (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 get knowledge about safety-related and other behaviour in real traffic, which is impossible or difficult to obtain by more traditional research methods.

The main objective of PROLOGUE is to demonstrate the usefulness, value, and feasibility of conducting a large-scale ND observation study in a European context.

The PROLOGUE project is aimed at road safety researchers and other stakeholders including car industry, insurance companies, driver training and certification organisations, road authorities, and governments.

The present deliverable is the final report from WP1 "Identification of potential areas of application and research". The report describes some research topics that are especially relevant and suitable for being investigated in future ND studies and it also presents a framework for defining more specific research questions in such studies.

A similar work being carried out within the US Strategic Highway Research Program 2 (SHRP2) is reviewed and is used as a source of reference for defining research topics. In the present report, however, a somewhat different framework for defining research topics is presented, compared to SHRP2.

The research topics are defined in terms of combinations of: 1) categories of driving behaviour and driver states, and 2) conditions under which driving behaviour may be observed.

The following *driver-related categories* were defined:

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

Each of these driver-related categories can be combined with any of the following *condition categories* to define a global research topic:

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

The matrix resulting from combining the two sets of categories above is considered to be a useful framework for classifying and defining more specific research questions for future ND studies. The specific research questions are supposed to comprise observing driver behaviour in relation both to road safety, traffic flow and environmentally friendly driving (eco-driving).

In addition to pure research, the ND approach can be used also in more applied settings, like driver training, training for environmentally friendly driving, for accident reconstruction, and for providing incentives to drivers for both safe and economical driving.

A survey among potential users of ND results showed that road safety was considered the most interesting general topic for such research – compared to environmental effects (eco-driving) and traffic management issues. Within the road safety area, “risk taking behaviour” and “crash avoidance behaviour” were the two more specific topics that were considered (very) important by the largest number of respondents. These areas are not covered very well in previous ND studies, but fit well into the matrix of research topics defined in this report.

In addition to the thematic research topics, there is a need for methodologically focussed ND studies. ND data can be used for validation of other research methods, like self-reports. There is also a need of validation of the ND approach itself, in order to assess whether the driver’s knowledge about her behaviour being recorded has any effects on that behaviour, in terms of refraining from certain socially unacceptable behaviours.

The possibility of investigating the research topics and applications described in this report depends heavily on the available technology for recording both driver, vehicle, road, and traffic parameters, and on the procedures for getting relevant driver samples for a large scale study. Technological and organisational issues are discussed in detail in other deliverables from PROLOGUE.

# 1 Introduction

The term “Naturalistic Driving” refers to a method for unobtrusive observation of driver behaviour, by means of in-car equipment, including video cameras recording both the driver and the traffic environment, as well as systems for logging various vehicle parameters.

The main objective of PROLOGUE is to demonstrate the usefulness, value, and feasibility of conducting a large-scale naturalistic driving (ND) observation study in a European context. The future large-scale study is assumed to investigate driver behaviour in relation to safety of road users, as well as other traffic related issues such as eco-driving and traffic flow/traffic management.

The PROLOGUE project is aimed at road safety researchers and other stakeholders including car industry, insurance companies, driver training and certification organisations, road authorities, and governments. The project is organised in different workpackages (WPs) covering several approaches in order to prove the value, usefulness and feasibility of this method:

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

The present deliverable is the final report from WP1 “Identification of potential areas of application and research”. Its purpose is twofold. The first aim is to specify research topics where the ND approach is expected to provide useful knowledge beyond what can be obtained by more traditional research approaches. The second is to describe and discuss practical applications using the ND approach to driver observation.

The present work is based on inputs from several different sources of information.

- PROLOGUE Deliverable D1.1, which is a literature survey of research topics and applications addressed in completed and ongoing ND studies.
- PROLOGUE Deliverable D1.2, which is a summary of user perspectives on ND, based on a survey carried out among the PROLOGUE User Forum.
- Draft deliverables from PROLOGUE WP 2, focusing on technical, methodological, and organizational aspects of ND studies.
- Expert knowledge of the research team, PROLOGUE partners, and User Forum members.

Since the previous PROLOGUE deliverables mentioned above were based on comprehensive literature surveys, no additional literature search was carried out for the present deliverable.

# 2 General description of the ND approach to road safety research

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 cars") 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. 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.

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 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 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 a type of studies that are similar to the ND approach is the so-called FOT ("Field Operational Test"), which involve the use of an instrumented vehicle in order to assess a particular piece of in-car equipment. This is 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. Thus, since there are gradual transitions between the various approaches, there is a need for defining ND, and 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
- No observer present in the vehicle[1]

Additional typical features are video recordings (primarily driver face and forward traffic scene), as well as GPS coordinates.

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

# 3 Defining research questions

In the present document research topics are discussed in terms of *driver-related categories* and *situational categories* (or *conditions*). By combining these two sets of categories we will present the research topics in the form of a matrix, where each cell is a combination of a driver-related category and a condition.

Research topics and questions can be described on different levels. First, there are the general or global topics or areas of research. In the present deliverable, the focus will be on that level, in order to show for which topics the ND approach is particularly well suited to have added value. Second, within each global area a very large number of more specific questions and hypotheses may be formulated for future studies. We will just give some examples of questions at that level, without ambition to present an exhaustive list.

# 4 The SHRP2 catalogue of research questions

The most comprehensive listing of research topics for naturalistic driving studies is the one that was developed as part of the ongoing SHRP2 project in the US.

Before presenting the PROLOGUE work, we will review shortly the approach used in SHRP2 to defining research questions. The main source from SHRP2 is the Phase 1 Report from project "S02 Integration of Analysis Methods and Development of Analysis Plan" (Boyle et al., 2009). The formulation of research questions started out from the traditional categorisation of risk factors into "Driver", "Vehicle", "Roadway" and "Environmental", and a description of the dynamic interaction between the factors. Each of those categories was further subdivided into "Dynamic" and "Static" factors. In addition, a differentiation was made between factors at the "trip level" vs. "event level".

Two different sets of specific research questions had been formulated in previous parts of the project (called projects S01 and S05, respectively), comprising a total of more than 400 questions. The specific research questions were grouped according to the mentioned categories. Based on this grouping of specific questions, a set of 27 "global research questions were formulated".

*Table 1. The most highly prioritized global research questions from SHRP2 (priority rank in parenthesis). Source: Boyle et al., 2009.*

| |
|---|
| How do dynamic driver characteristics, as observed through driver performance measures, influence crash likelihood? (1) |
| What impacts do roadway countermeasures have on lane-keeping performance? (1) |
| How does driver distraction influence crash likelihood? (1) |
| How do aggressive driving behaviors influence crash likelihood? (1) |
| How does driver fatigue influence the likelihood and type of crashes? (1) |
| How do advanced driver support systems influence crash likelihood? (1) |
| What is the influence of driver impairment on crashes and driver errors? (1) |
| How does the turn lane configuration influence behavior and crash risk? (1) |
| What variables or pre-event factors are the most effective crash surrogate measures? (1) |
| What explanatory factors are associated with crashes or crash surrogates and what analytical models can be developed to predict crash or crash surrogates? (1) |
| How do roadway features influence crash likelihood? (2) |
| How do signage, lighting conditions, and other traffic control related countermeasures influence crash likelihood and driver performance? (2) |
| How do static driver characteristics influence crash likelihood? (3) |

Next, the 27 global questions were prioritized on the basis of a decision tree with the following 7 levels:

A. Is the question safety relevant and focused?
B. Does it relate to a potentially high number of fatalities?
C. Does it require data beyond what is currently available?
D. Does the question require data about driver behaviour?
E. Is naturalistic data the best way to address this question?

F. Can we implement a straightforward intervention?

G. Does this provide broad insights into driving safety?

Starting with level A, if the answer was “Yes”, the research question was passed on to level B, and so on. If the answer was “Yes” at all levels from A to G, the question was given priority 1. If the answer was “No” at level G, the priority was 2, if “No” at level F, priority was 3, and so on.

Out of the 27 SHRP2 global research questions, 13 satisfied the criteria A through E above. These are shown in Table 1. They represent a total of 160 specific research questions. For an overview of the specific research questions we refer to Boyle et al. (2009).

# 5 The present approach to defining research topics and questions

Our presentation of research topics will be based to a large extent on the SHRP2 work, with some additions and adaptations to European conditions. The SHRP2 work is very detailed with specific research questions (Boyle et al., 2009). In our work we will formulate somewhat more general research topics, and leave the detailed specifications 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.

In the present report a somewhat different approach to defining global research questions is taken, compared to the SHRP2 work. The first step is a categorization of driving behaviour (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 6 specific categories plus 2 more general ones (combinations of conditions, and high-level topics), yielding a total of 8 categories for conditions.

Finally, the driver-related categories and the conditions/background categories are combined in a matrix with 72 cells (9 driver-related categories by 8 conditions). Those 72 combinations can be considered as *global research topics.*

Each cell can then be filled in with specific research questions from different sources.

Before describing the different categories in more detail, we will discuss some general features of the ND approach regarding the possibilities of collecting basic information for the purpose of estimating crash risk, which then can be applied to the different research topics.

## 5.1 Exposure and risk

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-reports, 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, and lots of near-miss incidents. By counting the occurrences of possibly risk related behaviours at the time of the crash or incident, and comparing the counts 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.

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.

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 probably is 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. 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 of enabling estimates of both prevalence and relative crash risk.

## 5.2 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. In addition to observing the driver by means of cameras and eye-tracking systems, recording a wide range of vehicle, road and traffic parameters is necessary for understanding driving behaviour. For an overview of relevant parameters in ND studies we refer to PROLOGUE Deliverable D2.2 (Groenewoud et al., 2010).

### 5.2.1 Distraction and inattention

Distraction and inattention is a research area that lends itself easily to ND studies. These phenomena represent one 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 observations of gaze direction. The quality of such data depends very heavily on the recording equipment (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 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.

When it comes to research on driver distraction factors in general, roughly one can say that 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.

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 a) the directly observed behaviour of the driver (e.g., eye glance pattern, number and position of hands on the steering

wheel), and b) the observed behaviour resulting from distracted driving, measured as position of the car, longitudinal and lateral accelerations, speed, following headway etc. The advantage of naturalistic studies over different types of experiments is that the associations between distractions and behaviour are observed in a naturalistic and real context, and the study situation is not artificial.

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 are subsequently analysed in detail, and the presence of distraction factors can be identified.

Third, in ND driving studies, the prevalence of distraction factors in crashes is often just a part of a broader analysis of relative risks associated with the various distraction factors. The main obstacle for estimating accident risk and relative risks in non-naturalistic studies is probably that it is difficult getting good exposure data on the various distraction factors. That is, one does not have information about how often drivers are exposed to 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.

Using ND data on prevalence of distractions in general as well as during accidents and near-accidents, relative risks (odds ratios) and corresponding PAR can easily be estimated.

*Secondary task engagement*

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

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, where as 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 exampling, 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 driving more risky, 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 drivers engaging in non-driving related secondary tasks because of relying too much on a warning system.

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

*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 and traffic 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.

### 5.2.2 Fatigue, sleepiness and other acute impairments

A second large crash cause is fatigue and sleepiness (or *hypovigilance*, to use 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.

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.

### 5.2.3 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 (1990b) in terms of slips, lapses and mistakes.[2]

The error categories according to Reason have been operationalised in the Driver Behaviour Questionnaire DBQ (Reason, 1990a; 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).

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 5.2.5 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.

### 5.2.4 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.

### 5.2.5 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 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] 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.

[3] SDLP = Standard Deviation of Lateral Position

### 5.2.6 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 to record 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.

### 5.2.7 Aggressive driving

So-called “aggressive driving” has been the subject of much recent research. Although it is a somewhat ill-defined 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 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 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.

### 5.2.8 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 & Forbes, 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.

## 5.3 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.

### 5.3.1 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 5.2. The driver-related categories listed there included relatively acute or temporary states, whereas the driver background categories 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.

*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 dependent on 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 such health implications for driving behaviour and accident risk, one needs a sample of drivers suffering from the disease in question. Alternatively, one can administer a self-report questionnaire to all participant drivers and have them indicate any diseases or mental health issues they are suffering from.

*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.

*Participant recruitment issues*

It may be a challenge to get enough variations in driver background factors when recruiting participants for an ND study. In order to draw conclusions about such relationships it is desirable to have drivers representing a wide range regarding the factors that are considered interesting. Thus, there may be a trade-off between considerations of representativeness of the sample and the need of a wide range of individual differences. For a further methodological discussion about recruitment of drivers for ND research we refer to PROLOGUE Deliverable 2.2 (Groenewoud et al., 2010).

### 5.3.2 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 such 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. (Gronewoud et al., 2010).

*Intersections*

Comparison of behaviour in 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.

*Roadway geometry*

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 gets wider, but less is known about effects on driver concentration. Are drivers e.g. 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?

*Road category*

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

*Signs and markings*

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 road conditions*

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 systems, and comparison of ND data between countries may give useful information about advantages and disadvantages of different road and traffic systems, forming the basis of future best practice recommendations.

### 5.3.3 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. 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. 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 may give useful additional knowledge as a basis of future improvement of most kinds of vehicle equipment.

### 5.3.4 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. 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 data base 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 motorised vehicles and vulnerable road users is site-based observation, which will be trialled in the PROLOGUE project, including observations at different intersections.

*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 such crashes. Understanding car driver behaviour in encounters with heavy vehicles is therefore of high importance, and may possibly give some indications regarding possible countermeasures.

## 5.4 The “behaviour x condition” matrix

The global research topics in this document are formulated in terms of *behaviour*. 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. Other behavioural indicators are included on the basis of 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 is a matrix where all combinations of the driver-related categories and the various driving conditions listed above are included. For each combination of a driver-related category and a driving condition, one or more examples of research topics or questions are listed. The examples are taken partly from SHRP2 catalogue of research questions described above (Boyle et al., 2009), and partly from the literature review documented in PROLOGUE Deliverable 1.1 (Backer-Grøndahl et al., 2010).

The cells of the matrix in Table 2 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. The specific topics and questions in each cell are listed only as examples, and the list is far from exhaustive. The examples of research questions and topics are not to be considered as recommendations for future studies, and some of them are even unclear and lack sufficient precision, so they are included here only as coarse indications of possible topics to address.

As mentioned before, the purpose of the current deliverable is to show the global research topics to be addressed, whereas detailed specification of the specific research questions will be a task for the possible large future ND project.

*Table 2. Matrix of research topics, based on combinations of driver-related categories and driving conditions.*

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

[1] From SHRP2 S05
[2] From SHRP2 S01
[3] From PROLOGUE D1.1

*(Table 2 continued)*

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

[1] From SHRP2 S05
[2] From SHRP2 S01
[3] From PROLOGUE D1.1

*(Table 2 continued)*

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

[1] From SHRP2 S05
[2] From SHRP2 S01
[3] From PROLOGUE D1.1

*(Table 2 continued)*

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

[1] From SHRP2 S05
[2] From SHRP2 S01
[3] From PROLOGUE D1.1

*(Table 2 continued)*

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

[1] From SHRP2 S05
[2] From SHRP2 S01
[3] From PROLOGUE D1.1

# 6 Non-safety related research topics

In addition to safety-related research, one purpose of the PROLOGUE project is to investigate the feasibility of using ND observation for research on driver behaviour in relation to environmental effects of driving and to traffic management issues.

## 6.1 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. So called “eco-driving” or “green driving” denotes a smart and smooth driving style that is assumed to reduce fuel consumption and greenhouse emissions. More specifically, eco-driving is characterised by (a) shifting to a higher gear as soon as possible, (b) maintaining a steady speed, (c) 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 gear-shift 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.

## 6.2 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 emission.

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, focussing also for example on drivers’ route choice in relation to travel time.

# 7 Non-research applications of ND

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.

Feedback based on ND observation systems has been used also in the graduated licensing phase for novice drivers driving on their own.

Another application has been eco-driving (see Section 6.1), 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.

A possible application in commercial driving could be to collect data for potential accident investigations; in other words, an extension of the “blackbox” or ADR (“Accident Data Recorder) currently in use in some vehicle fleets. This application is not yet a reality as a standard for private vehicles, because considerations of privacy protection necessitate consent from each involved person.

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. There are few examples of such use, and there is a lack of evaluation studies assessing to what extent drivers change their behaviour just as a consequence of the recording equipment.

# 8 Methodological research topics

## 8.1 Validation of alternative methods

In addition to the research topics that were summarised in Table 2, 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 as an alternative to other and more traditional methods, but rather 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.

## 8.2 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.

## 8.3 Validity of ND itself

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 such 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. 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.

## 8.4 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, making possible 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.

# 9 User perspectives

## 9.1 User survey

In order to collect opinions and viewpoints of potential users of ND results, a survey was carried out among the members of the PROLOGUE User Forum. The survey is published in a separate deliverable (van Schagen, de Craen, van Nes, and Eenink, 2010), and we refer to that for further details. The survey will be described briefly below and the main results will be presented.

A total of 137 mainly European professionals in the area of road transport and related areas, most of whom being members of the PROLGUE User Forum, were contacted by email and invited to fill in an internet-based questionnaire. The respondents represented governments, industry, research organisations, road user organisations, and some other organisations. A total of 72 persons responded to the survey.

## 9.2 Interest ratings of main topics

After reading a general introduction about the PROLOGUE project and ND, the respondents were asked to provide some background information, after which they had an option to read more about ND applications before responding to further questions. Then they were asked to indicate which of the following areas they would "consider interesting to investigate with the use of a large-scale European Naturalistic Driving Experiment":

- Road safety
- Eco driving or environmental effects of road traffic
- Traffic management
- Other (specify)

Road safety was marked as interesting by 92% of the respondents. For eco driving/environment the percentage was 61, and for traffic management 46. It was not surprising that road safety got the highest score for interest since this area has been the main focus of most ND studies so far. In addition, there may be a sampling bias, since people working with road safety are probably over-represented in the User Forum.

## 9.3 Specific predefined topics

Next, the respondents were asked to rate the importance of each of 17 specific topics of investigation on a 4-point scale from "Very important" to "Not at all important". The 17 topics were grouped into 3 categories: "Road safety topics found in literature review", "Eco driving and traffic management", and "Road safety topics not investigated yet with naturalistic driving method". The topics are listed in Table 3, with the percentages of respondents rating each topic as "very important" or "important".

The topics rated as important or very important by the largest number of respondents were "Risk-taking behaviour" and "Crash avoidance behaviour". It is notable that neither of these topics has been extensively studied in previous ND projects, and they are therefore likely topics for future studies. A general finding is that most topics are rated as important by a majority of the respondents. With the exception of two topics ("vehicle type" and "cross-country issues") 58 % or more rated each item as "important" or "very important".

When considering implications of the user priorities for identifying specific research questions, one should keep in mind that some important research issues may possibly not be

suitable for being validly investigated by ND studies. One example is alcohol use, since drivers volunteering for participation in ND studies can be expected to be less likely to drive under the influence, compared to the average driver. Thus, to be included in a final list of research topics for ND research, a topic should be considered to be both important and possible to investigate appropriately in an ND study. For some issues, alternative methods may be more appropriate.

*Table 3. Specific topics of interest among PROLOGUE User Forum members. Percentage of respondents rating each topic as "very important" or "important"*

| | |
|---|---|
| Pre-crash behaviour | 86 % |
| Driver condition (fatigue, stress, use of medication) | 85 % |
| In-vehicle safety support systems (cruise control, ISA, navigation, warning systems) | 88 % |
| Distractions inside the vehicle (Passengers, mobile phone use, eating) | 83 % |
| Normal behaviour (gap acceptance, overtaking, gear choice) | 88 % |
| Driver characteristics (gender, age) | 81 % |
| Distractions outside the vehicle (advertisement) | 58 % |
| Driver training | 64 % |
| Risk-taking behaviours (speeding, alcohol use) | 93 % |
| Crash avoidance behaviour | 90 % |
| Vulnerable road users (pedestrians, cyclists) | 75 % |
| Situational influences (weather conditions, traffic intensity, time of day) | 78 % |
| Roadway design (road width, line marking, road side) | 68 % |
| Vehicle type (size, weight, brand) | 31 % |
| Cross-country issues | 45 % |
| Environmental effects (eco-driving, gear change behaviour, toxic emission) | 65 % |
| Traffic flow (traffic jam behaviour) | 61 % |

## 9.4 Additional topics of interest

The respondents were asked if they could think of additional topics that would be possible and important to investigate in a future large-scale ND study. Here we have listed some of the suggested additional topics considered most relevant for ND studies (see van Schagen et al., (2010) for a complete list):

- Visual attention of the driver
- Low-speed manoeuvres, as parking
- The influence of new co-operative systems on drivers' behaviour
- eSafety effectiveness
- Distraction from children and other passengers
- The validity of performance indicators
- Effects of platooning

- Motorcycles, e.g. driver-machine-roadway interaction and car drivers' detection of and accommodation to motorcycles
- Speed changes as a function of the speed of other vehicles, e.g. overtaking cars, cars ahead
- The effect of information/education on driving styles and the duration of the effect
- Feedback on driving (experience) by video
- Human errors and violations; identification of their leading factors and the set-up of a proactive system (towards a resilient transport system)

It is notable that many of the suggested topics are further specifications of the predefined topics. Furthermore, these topics seem to fit well into the matrix of research topics, and thus the information from the survey can contribute to filling in parts of the matrix.

## 9.5 Differences between subgroups and countries

For the purpose of comparing countries with different levels of road safety, the 18 countries represented in the survey were divided into two groups based on mortality rate (road fatalities per million inhabitants), and responses were compared between respondents from the two groups. In general, there was a high degree of agreement between the two groups of countries. Respondents from the higher mortality countries, however, showed a higher interest in most of the safety-related topics, compared to the lower-mortality countries. It is further notable that respondents from higher-mortality countries seemed to be less interested in environmental effects and more in cross-country issues than the respondents from the lower-mortality countries. It is, however, difficult to draw firm conclusions about differences between countries, since the sample is relatively small, and nationality may be confounded with type of organisation.

Concerning organisation types, the results seemed to indicate that national and regional governments may be a little more interested than the other respondents in the non road safety topics such as traffic flow/congestion and environmental issues.

# 10 Technological and organisational aspects

The growth of ND research during the recent years results to a large extent from the technological development in the direction of smaller, more efficient and cheaper recording equipment. Since this development is likely to continue, and the research activities should be adapted to what is possible with the best technology available, the definition of research topics and questions should be an ongoing process. Questions that cannot be answered satisfactorily today may be investigated with good results tomorrow. For example, unobtrusive recording of visual fixations, based on mixing video recordings of eyes and traffic scenes, is still complicated without a calibration process. This implies that most ND applications still use rather coarse classifications of gaze direction (e.g., fixating on objects inside vs. outside the vehicle), whereas in laboratory settings or in simulators the point of fixation can be determined more precisely, i.e., which object exactly the person is looking at. However, in the near future it may be possible to get the same precision in the ND setting as in the laboratory.

Another challenge is the recruitment of representative samples of participants. The ND approach represents a potential threat against privacy, which may imply a certain self-selection of volunteering participants. In the presentation of research topics in this document it is assumed that it is practically feasible to get driver samples that are sufficiently representative for the driver population, and also large enough.

However, the representativeness of volunteer drivers in ND studies is a relevant research topic by itself, which has to be addressed in an eventual future large-scale study.

For further discussion of the technological and organisational aspects of ND studies we refer to the deliverables from WP2 of the PROLOGUE project (Welsh et al., 2010; Groenewoud et al., 2010).

# 11 Implications for future research and applications

The matrix of research topics that is presented in this report should be considered primarily as a framework of a database for showing the wide range of possibilities for a future large-scale European ND study. Each cell of the matrix could possibly include a long list of specific research questions (in addition to the few examples that are already listed), thus possibly resulting in a very large database. For the future study, however, a selection has to be made from that database, in order to identify a limited number of strategic fields, with corresponding research questions.

The identification of some strategic focus areas for future research should be initiated in subsequent workpackages of PROLOGUE, primarily in workpackage 4, which is supposed to develop recommendations for the large-scale future study. The strategic areas have to be exemplified by some specific research questions within the PROLOGUE project, whereas the full detailed specification work is supposed to be part of the large-scale project itself.

It should be acknowledged that there may be some complex research questions that are not captured adequately by any single cell of the research topic matrix. Thus, it will be a challenge for the final identification of strategic research fields to consider the possibility of combining various cells.

In addition to forming the basis for selecting strategic areas for ND research, the matrix is supposed to be useful for additional analyses of research questions beyond those implied by the defined strategic areas.

Both the review of previous and ongoing research and the survey among User Forum members have shown clearly that the main focus and interest for ND research until now has been within the road safety area, and a large majority of the identified research issues and topics are safety related. There is, however, nothing inherent in the ND approach which limits its fields of applications to safety. On the contrary, ND studies are suitable for investigating all observable aspects of driver behaviour, also those related to issues of environmental issues and traffic flow, which are the two main aims that are supposed to be emphasised in the PROLOGUE project in addition to safety. It should be noted that these two issues are interrelated, since reduced traffic flow has obvious environmental effects in terms of fuel consumption and emission. With the strong political and public interest in environmental issues it seems particularly urgent for the remaining work in PROLOGUE to develop relevant research topics and questions also within this field. It seems important to establish connections both with environmental organisations and with manufacturers of vehicles using alternative sources of energy. Both electric and hybrid vehicles are interesting alternatives to include in future ND studies. An interesting specific research question related to environmentally friendly driving is for example how different types of feedback to the driver regarding fuel consumption can affect driving patterns and indirectly emissions.

Realisation of a future large-scale study presupposes the identification of research topics that are both particularly suitable for being investigated by ND studies and considered important and relevant by policy-makers, industry, and other users. Thus, good communication with the User Forum, and taking care to include all relevant groups of users, will be important in the remaining work within PROLOGUE.

# 12 Conclusions

The naturalistic driving approach makes it possible to get knowledge about safety-related and other behaviour in real traffic, which is impossible or difficult to obtain by more traditional research methods.

The present report describes some research topics that are especially relevant and suitable for being investigated in future ND studies and it also presents a framework for defining more specific research questions in such studies.

The research topics are defined in terms of combinations of: 1) categories of driving behaviour and driver states, and 2) conditions under which these behaviours may be observed.

The matrix resulting from combining the two sets of categories above is considered to be a useful framework for classifying and defining more specific research questions for future ND studies.

It is clear that most research topics and questions that have been addressed in ND studies so far are related primarily to road safety. It is important to note, however, that this methodological approach is well suited also for studying additional important transportation issues like traffic flow and environmentally friendly driving. There is a need of further specification of relevant research questions within these areas.

In addition to pure research, the ND approach can be used also in more applied settings, like driver training, training for environmentally friendly driving, for accident reconstruction, and for providing incentives to drivers for both safe and economical driving.

A survey among potential users of ND results showed that road safety was considered the most interesting general topic for such research – compared to environmental effects (eco-driving) and traffic management issues. Within the road safety area, “risk taking behaviour” and “crash avoidance behaviour” were the two more specific topics that were considered (very) important by the largest number of respondents. These areas are not covered very well in previous ND studies, but fit well into the matrix of research topics defined in this report.

In addition to the thematic research topics, there is a need for methodologically focussed ND studies. ND data can be used for validation of other research methods, like self-reports. There is also a need of validation of the ND approach itself, in order to assess whether the driver’s knowledge about her behaviour being recorded has any effects on that behaviour, in terms of refraining from certain socially unacceptable behaviours.

The possibility of investigating the research topics and applications described in this report, depends heavily on the available technology for recording both driver, vehicle, road, and traffic parameters, and on the procedures for getting relevant driver samples for a large scale study.

A particularly interesting and innovative approach that will be tentatively assessed in PROLOGUE is the use of synchronised in-vehicle and site-based observations. In addition to providing useful knowledge about interactions between motorised vehicles and vulnerable road users, site-based data may also give some input to a tentative validation of the in-vehicle behavioural observations.

# 13 References

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# List of Tables

# List of Abbreviations

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| CO: | Confidential Deliverable |
| PU: | Public Deliverable |
| QA: | Quality Assurance |
| RE: | Restricted Deliverable |
| WP: | Work Package |
| ND: | Naturalistic Driving |
| SHRP2: | Strategic Highway Research Program 2 |
| FOT: | Field Operational Test |
| PAR: | Population Attributable Risk |
| IVIS: | Intelligent Vehicle Information System |
| ADAS: | Advanced Driver Support System |
| SDLP: | Standard Deviation of Lateral Position |