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10/05/2010	Draft after review: integrated changes from UNIFI (reviewed documents and general parts).

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Nomenclature

ACN	Automatic Collision Notification
ADAS	Advanced Driver Assistance System
BAC	Blood Alcohol Concentration
CAN	Controller Area Network
CMV	Commercial Motor Vehicle
COM	Component Object Model
CVO	Commercial Vehicle Operations
DAS	Data Acquisition System
DBQ	Driver Behaviour Questionnaire
DDWS FOT	Drowsy Driver Warning System Field Operational Test
E-OBD	Europen On-Board Diagnostics
FARS	Fatality Accident Reporting System
FOT	Field Operational Test
GEE	Generalized Estimation Equation
GES	General Estimates System
GPS	Global Positioning System
GUI	Graphical User Interface
ID	Identification
ISA	Intelligent Speed Adaptation
ITS	Intelligent Transportation System
IVIS	In-Vehicle Information System
LIN	Local Interconnect Network
MOST	Media Oriented Systems Transport
NAS	Networked Attached Storage
ND	Nomadic Device
NDS	Naturalistic Driving Study
NRS	Naturalistic Riding Study
NTDS	Naturalistic Truck Driving Study
OR	Odds Ratio
PAR	Population Attributable Risk
PI	Performance Indicator
PTW	Powered Two-Wheeler
SAS	Statistical Analysis Software
SPSS	Statistical Package for the Social Sciences
SQL	Structured Query Language
SUV	Sport Utility Vehicle

T-LOC	Traffic Locus of Control
TTC	Time to collision
US	United States
USB	Universal Serial Bus
VTTI	Virginia Tech Transportation Institute
WP	Work Package

Executive summary

2-BE-SAFE project aims to study powered two wheeler (PTW) rider behaviour in order to provide basic knowledge for enhancing the safety of PTW riders. A number of innovative research techniques are used in the study, all of them sharing the same objective: to understand and characterize PTW rider behaviour.

In Work Package 2 of 2-BE-SAFE a naturalistic riding study will be undertaken. A naturalistic riding study is one in one which the PTW is instrumented with video and other sensors (e.g. accelerometers and inertial measurement unit) which enable the natural behaviours of the rider and the vehicle to be observed and recorded in real time. The design and execution of a naturalistic riding study is a complex task, which requires appropriate consideration of many issues, including technical and ethical/legal issues. In order to implement an efficient study, it is necessary to build on previous naturalistic driving studies involving cars and trucks.

2-BE-SAFE Work Package 2.1, which is the focus of this report, is the preliminary task for the implementation of a naturalistic riding study and it aims to review previous relevant literature and studies in search of information useful for the design of the naturalistic riding study. Several documents were reviewed for this report, including naturalistic driving studies (NDSs) and field operational tests (FOTs). These two types of studies use similar approaches to measure and record driver and vehicle behaviour in real time using instrumented vehicles, but are slightly different in scope:

- NDSs **observe** the natural behaviour of a driver/rider while interacting with the surrounding environment during driving/riding tasks, and collect observational and performance data.
- FOTs **evaluate** one or more functions (e.g., advanced driver assistance systems) under normal operating conditions in environments typically encountered by the host(s) vehicle(s) using quasi-experimental methods. They seek to quantify the impact of functions on driver performance and safety, and driver acceptance of them.

In this report, the most significant NDSs and FOTs were reviewed to extract useful information which could support the design stage of the 2-BE-SAFE naturalistic riding study. The main topics of interest in the literature review were the organizational requirements, research methods, and procedures required to conduct and analyse a naturalistic riding study. In particular, the following information was extracted from the studies reviewed: research questions; parameters recorded and tools/sensors used for data acquisition; behaviours observed; procedures and methods (implementation of the study, equipment installation, data collection, data download and storage, subject recruitment / briefing / training); ethical and legal issues; data analysis tools and methods.

The results of the literature review were condensed into a set of recommendations for the next WP2 activity (A2.2; design of the naturalistic riding study). The information obtained from the reviewed documents was filtered to take into account the specific requirements of a naturalistic riding study implemented with PTWs. The following key recommendations emerged from this activity:

- There must be utmost consideration of the ethical issues, with a detailed communication of the rights and duties to the persons involved in the study and an efficient protection of the data (section 7.1);
- There must be analysis of legal issues in parallel with the technical ones. Although it is impossible to have an exhaustive list of the legal implementation issues, which apply to all naturalistic studies (or FOTs), a checklist of the major topics was indentified (section 7.2) and it is suggested that teams ask for legal support within their organizations in the preparatory phase in order to anticipate possible problems. As a specific point within legal issues, the vehicles should undergo a new approval

process after the installation of sensors or, as a secondary alternative, a risk assessment should be performed and the results should be included in the document for the informed consent of the participants;

- There must be a clear definition of the goals of the study (research questions and hypotheses) and cross-verification with the availability of appropriate instrumentation;
- There must be in-depth characterization of the subjects involved in the study. In the literature reviewed this was performed with different depth, but in the major studies the following issues are taken into account:
    - demographical data;
    - driving experience;
    - personality and attitude towards driving;
- There must be definition of a consistent set of data. In previous studies video signals are always included (alone or in parallel with other signals), although they do not show a high level of reliability (section 6.4). Other signals common to the major research activities are:
    - GPS position;
    - accelerations;
    - speed;
    - pedal use (in cars);
    - steering angle;
    - turn-signal use;
- A data acquisition strategy must be developed. All research activities performed a continuous data acquisition with post-processing based on automatic triggers, which allowed false positive events in order not to lose any real positive events. The selected events were always reviewed by reductionists before being included in the database;
- A common policy for data download and storage must be developed in order to avoid possible loss of part of the dataset. Suggestions are made for the adoption of safe practices reported in section 6.5;
- Implementation protocols must be developed, which define univocal actions for all teams, particularly in the following stages of the research:
    - subject recruitment;
    - subject briefing;
    - data processing;

  Although the availability of common documents and shared practices is relevant throughout the research, implementation protocols must cover these aspects in order to avoid systematic biases to the study. In the data processing an additional effort is necessary in order to guarantee a similar performance level for the reductionists of the different teams and thus to obtain a reliable dataset. It is suggested that a reliability check procedure is considered which is compatible with the resources available for the study.
- A common database structure and coding scheme for the events must be defined in order to use the data in aggregate modality.

Lastly, as suggested by the EC-funded Field Operational Test Support Action (FESTA) consortium, piloting of all equipment, methods and procedures is necessary to eliminate as far as possible problems that are not envisaged in the design phase.

1. Introduction

The higher risk of fatalities for PTW riders is well known from European accident statistics and several research projects (APROSYS SP4, SIM, PISA, MYMOSA, SAFERIDER, and SMART RRS) have proposed technical solutions in different sectors (passive, integrated or active safety) in order to save riders' lives. Nonetheless up to now no project has focused in-depth on rider behaviour, like 2-BE-SAFE is currently doing, in order to understand the strategies and priorities of users when they ride a PTW and their behaviour in real-world conditions. The latter aspect is the objective of work package 2 and it requires the setup of a naturalistic riding study.

Naturalistic observational studies are a specific observation technique, which allow researchers to gather data about driver/rider behaviour in unconstrained and uncontrolled, thus natural, conditions. According to the aim of the study critical or normal conditions can be of interest for the researchers. Since the 2-BE-SAFE project aims to contribute to the enhancement of safety, the focus of the naturalistic riding study in WP 2 will be on critical events such as near-misses, as they provide the most promising *source* of information to understand: 1) why accidents happen; and 2) what riders do to avoid them.

The naturalistic observational technique involving instrumented vehicles has never before been applied at European level to riders and PTWs, but it has been used successfully in cars and trucks in other parts of the world. The organization of a naturalistic riding study poses several additional problems to the general complexity of a naturalistic driving study, which are mainly caused by the different vehicle type (e.g. the greater degrees of freedom of movement of the PTW) and the necessity to adapt the methodology to the specific case of riders. For these reasons WP2 started its activities with a review of naturalistic driving studies (NDSs), which constitutes the objective of activity 2.1. The review included also consideration of field operational tests (FOTs), even though their aim is different from a naturalistic study. The aim of FOTs is to evaluate one or more functions under normal operating conditions in environments typically encountered by the host(s) vehicle(s) using quasi-experimental methods). Nevertheless both kinds of studies have common methods and procedures for measuring, recording and analysing driving behaviours. The common points are evident from the V-diagram of the FESTA project (**Figure 1**; [12]): except the V extremities ("*Function identification […]*"; "*Use cases*"; "*System and […]*" and "*Socio-Economic […]*") all actions are relevant also for a naturalistic study.

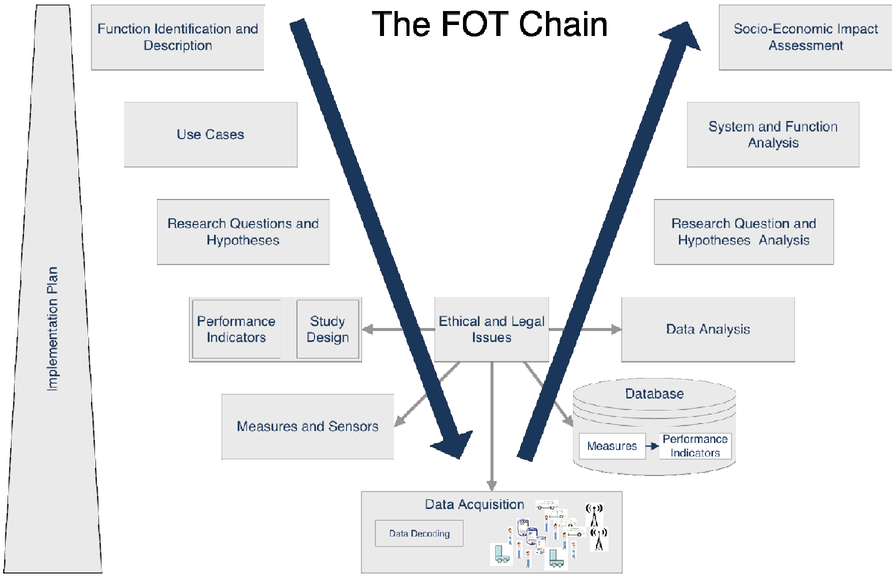


Figure 1: FOT chain [12].

At present there are no concluded naturalistic studies involving Powered Two-Wheelers and there is only one ongoing research activity, initiated by the Virginia Tech Transportation Institute (VTTI), that is concerned with the naturalistic observation of motorcycle riders using instrumented motorcycles. However, no public deliverables are currently available for that study. Thus the design of the naturalistic study planned within the 2-BE-SAFE project can rely only on previous similar experiences of the partner institutions and on the knowledge derived from the literature review.

The reviewed studies are here listed with a short abstract, in order to support the reading of the main body of this document:

- **100-Car Naturalistic Driving Study:** the study aimed to collect large-scale, naturalistic driving data of car drivers. The research comprised three stages: conduct test planning activities; conduct a field test; prepare for large-scale field data collection effort (reports are available only for the first two parts). The data set is made of approximately 2,000,000 vehicle miles, 43,000 hours of data, gathered with 241 primary and secondary data with a data acquisition period of 12-13 months per vehicle. The data were processed to create a database of events, structured similar to an epidemiological crash database, which included crashes, near-crashes and other conflict events. The main results of the second stage include an analysis of rear-end events, lane change events, the role of inattention, and the relationship between levels of severity. In addition an analysis of the implemented methodology was performed to identify critical issues that had to be removed during the third stage of the research.
- **Field opErational teSt supporT Action (FESTA):** FESTA (Field Operation Test Support Action) was a project aiming at developing a harmonised methodology for the conduct of Field Operational Tests across Europe and yielded recommendations for carrying out this type of study. The project deliverables as well as the FESTA Handbook include information on each phase of Field Operational Tests (FOT) and give support for the planning of a FOT by stressing the important aspects to consider.
- **Test Site Sweden FOT:** a small-scale FOT was performed in order to assess the full methodology-chain involved in a FOT: data acquisition, data upload, data storage, data search, and data analysis. Some technology – related developments include: data acquisition system collection of data from the vehicles, database development, and analysis software development. An investigation of why and where lateral jerks occur during driving was carried out to illustrate the analysis process.
- **Driver distraction in commercial operations:** this study investigated driver distraction in commercial motor vehicle (CMV) operations. Data from two earlier studies (a naturalistic driving study and a field operational test) were combined to create a data set for 203 CMV drivers and 55 trucks. A total of 4,452 safety-critical events were identified in the data set. Analyses were performed on the data to calculate the increase in risk of being involved in a critical event when distracted, and the proportion of crashes in which distraction was a contributing factor.
- **A comprehensive examination of naturalistic lane-changes:** this study analysed the nature and severity of lane changes in a naturalistic driving environment. The participants were sixteen commuters who normally drove more than 40 km in each direction. Data were obtained on the behaviours and parameters associated with lane changes, such as data on the frequency duration, urgency, and severity of lane changes in regard to manoeuvre type, direction, and other classification variables. A subset of the full data set was then analyzed in greater depth, with variables such as turn signal use, braking behaviour, steering behaviour, eye glance patterns, and forward and rearward area analysis. The concept of safety envelope for lane changes

was developed, and the data were used to provide recommendations for designers of lane change CAS.

- **Naturalistic driving observation to investigate distraction exposure and IVIS pattern of use: interests and constraints of the approach:** this work evaluates the possibility to investigate the potential impacts of IVIS on driving behaviour by means of naturalistic driving observations. The approach is described, including suitable research issues addressed by this method, the available technology and the constraints of the approach. The latter refer to ethical issues, the selection of the subject sample, suitable servicing processes, data coding issues and statistical analysis constraints.
- **Distractions in Everyday Driving:** the study involved two phases: the first one involved identifying the major sources of distraction that contribute to traffic accidents and to developing a taxonomy of the identified distractions. The second phase, the review of which provides data for this report, involved a naturalistic driving study, the aim of which was to validate a methodology that was developed to determine the occurrence of various distractions whilst driving and to investigate the effect of driver distractions on driving performance.
- **Naturalistic Studies of Driver Assistance System Use:** the document provides a rough overview of several issues that have been raised following five FOT's implemented by UMTRI in the period 1993-2005. The tested systems included anti-brake locking system (ABS), cruise control systems (including Adaptive Cruise Control), and crash warning systems including curve and lateral drift warning systems. Two FOTs involved truck drivers and the remaining ones passenger car drivers. The issues of system evaluation, tools and techniques are discussed. Some findings from one of the studies were discussed.

These studies were reviewed to identify the organizational issues, methods, and procedures to be considered in setting up a naturalistic riding study. Specifically the documents were analysed to extract the following information:

- research questions;
- parameters recorded and tools/sensors used for data acquisition;
- behaviours observed;
- procedures and methods, with a specific attention to implementation of the study, equipment installation, data collection, data download and storage, subject recruitment / briefing / training;
- ethical and legal issues;
- data analysis tools and methods.

All these topics will be analysed in thematic sections of this report, with subsections dedicated to each of the reviewed studies.

2. Research questions

In all NDS and FOT research studies an implementation plan must consider from the earliest stage the research questions of interest, in order to derive accordingly all the subsequent actions. In the following the research questions of the reviewed studies are listed in order to provide guidance for the definition of the research questions of the Naturalistic Riding Study (NRS) and to better understand the information retrieved from the literature review.

2.1. 100-Car Naturalistic Driving Study

The research has three macro groups of research questions on:

- driver behaviour and performance;
- distribution of events.
- evaluations.

Regarding driver behaviour and performance, the 100-car Naturalistic Driving Study focused on these questions:

- Which are the contributing factors and dynamic scenarios involved in each category of events (incidents, near-crashes, crashes)?
- How can “near-crash” be defined using quantitative measurements?
- Which are the differences between:
    - one week of field data and one year of naturalistic driving data?
    - one month in a leased versus privately owned vehicle?

In second macro group the research questions are:

- Which are the contributing factors and dynamic scenarios in rear-end events?
- Which are the contributing factors and dynamic scenarios in lane change events?
- In rear-end events, which is the frequency distribution of incidents, near-crashes, crashes according to the following criteria?
    - per vehicle mile travelled;
    - in relation to contributing factors;
    - in relation to corrective actions;
    - in relation to transition events.
- In rear-end events, which are the dynamics and precipitating factors? Which is their frequency distribution according to vehicle mile travelled; initial kinematic condition; primary contributing factor?
- Which is the distribution of inattention types for each rear-end – lead vehicle scenario?
- Which is the characterization of each rear-end – lead vehicle scenario according to the Heinrich’s triangle?

In terms of evaluation of research instrumentation and methods the research questions are:

- Which was the performance of the hardware used to instrument the cars (e.g. failure rates)?
- Which was the performance of the:
    - data reduction plan?
    - triggering methods?
    - data analysis procedure?

2.2. FESTA

The FESTA handbook [12] provides general guidelines about research questions when testing different systems (mainly Advanced Driver Assistance Systems (ADAS) and In-Vehicle Information Systems (IVIS) for vehicles – both autonomous and cooperative systems – and nomadic systems). These research questions can be related to system use, system impacts system acceptance etc., and in broad terms are the following:

- Which factors affect system use?
- How do different driver characteristics affect system use?
- How does system usage affect road safety?
- How does system usage affect personal mobility?

- How does system usage affect traffic conditions?
- How does system usage affect the environment?
- How does system usage affect the design of policy?
- How does system usage affect business models?
- What are the implications for system design & development?
- How does system usage affect the public?

The investigated research questions of a study should be directly linked to the aims of the study. For each research question several sub-questions can be investigated. Using as an example the last question "how does system usage affect the public" the sub-questions could be [12]:

- How will public information/education be updated to deal with issues related to system use?
- What changes in legislation need to be implemented to incorporate issues related to system use?
- How can inclusive access to systems be achieved?
- How can data protection be ensured?

2.3. Driver distraction in commercial operations

The following research questions were addressed:

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

2.4. Other studies

In the AAA distraction study [16] the aim was the identification of the major sources of driver distraction, the analysis of their occurrence in everyday driving and the potential consequences of driver distraction on driving behaviour and hence driver road safety. The primary research questions that were sought to be addressed were:

- What are the distracting activities that drivers engage in?
- How often do drivers engage in different distracting activities?
- Are there age and sex differences in drivers' engagement in distracting activities?
- Under what conditions do drivers engage in distracting activities?
- What are some (as not all can be identified – due to study constraints) of the effects of driver distraction on driving performance?

In addition to the aforementioned questions, the validation of the methodology for loging distraction was also a “research question” itself.

3. Parameters recorded

Certain parameters were recorded in order to answer the research questions mentioned above. These are described below.

3.1. 100-Car Naturalistic Driving Study

In the 100-Car Naturalistic Driving Study [20] the recorded dataset consisted of:

- approximately 2.000.000 vehicle miles of driving;
- almost 43.000 hours of data;
- 241 primary and secondary driver participants;
- 12 to 13 month data collection period for each vehicle; 18 month total data collection period.

During the study the following parameters were recorded ([20], p.10):

- distance to lead and following vehicles;
- longitudinal and transversal acceleration;
- gyroscopic signals;
- GPS position;
- brake activation (light);
- turn signal;
- throttle;
- speed;
- mileage;
- 5 video signals (driver’s face and driver side of the vehicle, forward view, rear view, passenger side of vehicle, and over-the-shoulder view for the driver’s hands and surrounding areas);
- lane position;
- activation of the incident pushbutton;
- audio (active only if an incident pushbutton was pressed);
- glare.

The structure of the data acquisition system is explained in chapter 5, while its installation in the vehicle is explained in section 6.3.

Besides vehicle and environmental data, the 100-Car Naturalistic Driving Study recorded also information on the primary drivers - i.e. the drivers contacted for the study, who were fully briefed (secondary drivers are relatives or other persons that drove the vehicles occasionally and without being informed about the study):

- demographic data;
- health status (visual acuity, hearing levels, previous health problems);
- habits (sleep habits);
- personality (five dimensions of normal personality; neuroticism, extraversion, openness, agreeableness and conscientiousness);
- driving behaviour (driving style “level of aggressiveness”, attitudes towards driving under different conditions, risk of crash involvement, historical information on traffic violations and accidents, seatbelt use and attitude towards the seatbelt use);

In addition a debriefing questionnaire, about events that occurred during the last year, was completed and, in case of a crash, also the driver's description of the crash. The test and questionnaires used to collect this information are reported in Table 9 (section 6.2).

3.2. FESTA

In general, FESTA suggests a number of parameters that are used to describe a situation and also to evaluate a system. These may fall into one of the following categories:

- System intrinsic performance
- Driver interaction with the system
- Effect of driver interaction with the system
- Driver characteristics
- Road Environment characteristics
- Other (e.g. driver acceptability and trust)

In addition the FESTA Deliverable 2.1 [7] recommends registering the following driver characteristics, recorded by means of questionnaires:

- **Demographic Characteristics**: gender, age, country, educational level, income, socio-cultural background, life and living situation.
- **Driving experience, driving situation and motivation:** experience in years and in mileage, professional, tourist, with or without passengers and children.
- **Personality traits and physical characteristics:** sensation seeking, locus of control, cognitive skills, physical impairments or weaknesses.
- **Attitudes and intentions:** attitudes towards safety, environment, technology.

Driving experience has a significant effect on individual crash risk even if age is controlled for. Driving experience can be measured by means of self-reports on overall mileage since licensing or current mileage per year. A combination of both is recommended as both measures do not have a very high reliability.

Personality traits may have direct impact on driving behaviour or may affect driving through the influence of attitudes and intentions. The representation of personality traits in the sample is important for the interpretation of the study outcomes. Two aspects of personality particularly interesting for research on unsafe driving and accidents are Sensation Seeking and Locus of Control. Besides, personality traits from Costa and McCrae's Five Factor Model of personality have been found to be related to driving behaviour. Personality traits are to be measured by the corresponding questionnaire, such as the Sensation Seeking Scale by Zuckermann, the Traffic Locus of Control Questionnaire (T-LOC) by Özkan and Lajunen or the Big Five Inventory by John and Srivastava. Francher et al. (1998, cited by [7]) developed a driver style test for the Intelligent Cruise Control FOT which may be of interest in naturalistic driving studies. This test uses drivers' speed and headway choice in order to classify the drivers into categories of aggressiveness. Those categories are hunter/tailgaters, extremists, planners, flow conformists and ultraconservatives.

The record of *attitudes and intention* should include self-reported driver behaviour, as registered by the Driver Behaviour Questionnaire (DBQ) which includes errors, lapses and violations. Furthermore, beliefs and intentions may be measured by means of a questionnaire based on Ajzen's Theory of Planned Behaviour.

Generally, the different driver characteristics are not independent, but may be highly related and influence each other. Combinations of them may have different influences on driving behaviour, a fact that is to be considered in analysis of data and interpretation of results.

In addition within the FESTA project [9], in its third section “Experimental environment”, there is discussion of how the road environment plays an important role in the design of an FOT:

- *experimental environment:* it is a critical element in a FOT, since it will determine the data that are collected and the ability to fulfil the objectives. There are two main reasons for designing the experimental environment:
  - to ensure that is appropriate for the systems being tested and research questions of interest;
  - to enable data to be analysed effectively.

  Environmental factors can be treated in several different ways, including:

  - explicitly included in a FOT because one is particularly interested in data connected to that environmental factor (e.g. motorway routes for lane departure warning);
  - explicitly included in a FOT because these environmental factors are part of the range occurring within a normal driving scenario (e.g. night time driving);
  - measured scientifically so that the data relating to that environmental factor can be included within post trial data analysis (e.g. vehicle headways);
  - recorded (in varying levels of details), so that portions of data can be excluded from analysis.

  According to the FESTA project [9], the following classes of parameters are of the most importance for a FOT study:

  - *road type*: it is the environmental factor that perhaps has the greatest dynamic influence on a field operational test (FOT) study. The main issues to do with road type that may arise during a FOT are:
    - road characteristics;
    - route choice;
    - temporary road/traffic variables;
    - the traffic encountered;
    - impact of road measures on driver behaviour;
    - pan – European road taxonomies.
  - *weather conditions*: they are hard to predict, control or measure accurately. However, weather conditions and associated factors such as ambient lighting conditions are a relevant aspect of the study. The main issues are:
    - the need to include data of a range of weather conditions;
    - confounding of data due to abnormal weather;
    - measurement of weather conditions;
    - combination and extreme weather factors.
  - *time of day and seasonal effects*: they have a considerable impact on data collection and further on data analysis. These temporal factors can usually be predicted and so is easier to deal with them. The main issues are:
    - influence on driver state;
    - disruption caused by external events;
    - influence on traffic levels;
    - impact on vehicle occupants;
    - light levels;
    - seasonal confounding of data collection;

    - influence on route choice.

- *geographical location*: it can be chosen because it is representative of the intended area of use for a vehicle/system. Also, it displays the characteristics needed to collect the specific data for the study. In some cases, the geographical aspects will be central to the functionality provided by a system. The main issues to do with geographical location that may arise during a FOT are outlined below:
    - the type of roads and localities present;
    - cultural issues;
    - population characteristics;
    - car ownership;
    - use of new technologies;
    - language issues;
    - traffic patterns;
    - infrastructure and data communication issues;
    - environmental information sources;
    - other transport options;
    - legal regulatory and enforcement environments;
    - logistical issues;
    - availability of other data.

Last, in terms of parameters that describe system use the following categories were indicated – (presented in this section under a slightly different classification than in the FESTA document):

- Driver behaviour (speed, reaction time etc.)
- System performance (e.g. false alarms, failure in detecting obstacles ahead etc.)
- Subsequent effect on system use (e.g. driver trust, switching off the system, driver irritation etc.)
- System impact on driver behaviour (e.g. speed variability, frequency of lane changing, route choice, driver distraction, driver exposure etc.)
- System impact on environmental conditions (e.g. measuring specific pollutants)
- System impact on traffic conditions (e.g. queues, travel time etc.)

Driver behaviour is mentioned twice, the difference being that in the first case no system is under operation, whereas in the second one the investigated system is operating. Apparently, the two categories would comprise almost the same parameters.

It must be noted once more that within FESTA a general overview of several possible parameters that can be investigated in an FOT was provided. However, when conducting a naturalistic driving study (or an FOT) the appropriate parameters need to be defined depending on the aim of the study and the means available for measuring them.

3.3. Test Site Sweden FOT

The Test Site Sweden FOT [18] acquired about 200 hours of driving data from about 100 vehicles. The main parameters recorded were:

- GPS (position, speed and time for synchronisation)
- acceleration (longitudinal and lateral)

- steering wheel angle
- pedal positions
- gear lever position
- yaw rate
- engine speed
- data from video (not specified)
- foot location (by sensors on pedals)
- activation of incident button
- demographic data from a questionnaire (sex, age, living place, date of driving license, mileage last year and total mileage).

3.4. *Driver distraction in commercial operations*

This project was a “secondary analysis”, using data sets from two previously completed naturalistic heavy-vehicle driving studies: the **Drowsy Driver Warning System Field Operational Test (**DDWS) FOT (Hanowski et al., 2008) and the **Naturalistic Truck Driving Study** NTDS (Blanco et al., in press).

Unfortunately, the individual parameters (performance indicators, situational variables, measures and derived measures) for each of the two previous studies were not reported in this study. Only high level descriptions of the recorded parameters were given, as follows.

DDWS FOT - Three types of data were collected by the data acquisition system in the first of these two studies: digital video, truck dynamic performance data (i.e., kinematic data; e.g., lateral and longitudinal acceleration, braking as well as truck-related measures (e.g., GPS, light level), and audio... The digital video file contained the video recorded continuously during each trip. The audio file derived from the driver pressing a Critical Incident Button, which enabled him/her to comment on incidents they believed were “notable” (Olsen et al., p. 18).

NTDS – The same three types of data were recorded. In addition, a Lane Tracker was used to derive data on lane positioning.

3.5. *Other studies*

In their naturalistic study of lane changes, Lee, Olson and Wierwille [1] also captured five channels of video recording: head/eye position, front view, rear view and rear sides. In the same study, with reference to vehicle and environmental data, the sensors recorded:

- speed
- steering
- acceleration
- use of pedals
- turn-signal use
- information about surrounding vehicles, processing the data of three radar units (one forward and two rearward).

Bonnard and Brusque [14] mention the necessity of a video recording system that captures what happens inside and outside the vehicle as a basis for naturalistic driving observations. In addition they recommend recording the vehicle parameters (speed, steering wheel angle, indicator use, etc.) via an E-OBD interface, by scanning the CAN (Controller Area Network)-bus or via specific additional sensors. The authors suggest including a GPS in order to collect information on the vehicle location and several accelerometers to measure longitudinal and lateral acceleration of the vehicle. They also mention the possibility to integrate advanced perception sensors (lane tracking system or radars about position on road and the surrounding traffic), although their relevance has to be evaluated in each specific study as they represent considerable costs. Therefore, the sensors should be chosen in accordance with the parameters that need to be recorded in order to answer the research questions of the specific study.

In [16] the recorded parameters can be classified under three distinct categories; driver distraction situations, contextual variables and outcome measures. The driver distraction category was essential as the study involved driver distraction and included conditions that were identified through video footage such as:

- talking on the telephone,
- eating/drinking,
- music/audio,
- smoking,
- reading/writing,
- grooming,
- occupant distraction,
- internal distraction, and
- external distraction.

The aim of recording contextual variables was to be able to identify under which conditions the driver would be be engaged in distracting activities. The variables that were recorded were the following:

- vehicle occupancy,
- weather and light conditions,
- road type (number of lanes, intersection),
- traffic conditions, and
- vehicle movement.

The outcome measures category involved parameters reflecting characteristics of driver behaviour and the reason these were included was to identify and demonstrate the effect of driver distraction (except for the first indicator) on driver behaviour and hence driver safety. The investigated parameters were:

- number of hands holding the steering wheel,
- position of driver eyes, and
- position in the lane and braking.

It must be noted that other variables (driver attention and driver workload, following distances and vehicle deceleration) would have also been useful for the specific study – as noted by the authors - however they were not available due to equipment and situational constraints.

In several studies it is stated that in order to facilitate data analysis, triggers can be set for special sequences of recorded data and, therefore, data that might serve as a trigger for interesting situations has to be included. Still, the data and video sequences will have to be checked by an expert as some behavioural information can only be found manually.

4. Behaviours observed

In this chapter the behaviours observed in previous naturalistic studies are reported. Although the riding actions and behaviours observed with PTWs will differ and some categories will be inapplicable, the information in this chapter can anyway help to define the basic behavioural categories. In addition the observed behaviours complete the general framework of the studies comprised of signals, sensors and behaviours.

4.1. 100-Car Naturalistic Driving Study

The 100-Car Naturalistic Driving Study ([3], [19], [20]) extracted from raw data an incredible amount of information, which exceeds the pure observation of driver behaviour and allows to create links with epidemiological databases (as stated in the objectives of the study).

In the following an elaboration of the 100- Car Naturalistic Driving Study is presented, which, without any quantitative information, presents a general overview of the driver behaviours observed in the study. Information on driver behaviour is distributed within the structure used to present the results, which is described in section 6.7.1 of this document. The behaviours are derived, for all the conflict types, from the categories of:

- pre-event manoeuvres;
- avoidance manoeuvres;
- driver factors, which includes four relevant subcategories:
  - wilful behaviour;
  - driver impairments;
  - driver proficiency error;
  - inattention to forward road, further divided into:
    - secondary tasks;
    - driving related inattention;
- post avoidance manoeuvres.

Due to the specific interest of the NDS organized within the 2-BE-SAFE project, which focuses on near-crashes, only near-crash data were processed to identify driver behaviours (Table 1 to Table 6). The complete body of results, which includes also information on the driver behaviours in crashes and incidents, can be found in Appendix C of the report on Phase II [20].

Table 1: 100-car observed behaviours - pre-event manoeuvres in near-crashes.

Description Conflict with		changing lanes	decelerating in traffic lane	going straight accelerating	going straight constant speed	manoeuvring to avoid a vehicle	merging	negotiating a curve	starting in traffic lane	stopped in traffic lane	turning left	turning right
lead vehicle		X	X	X	X	X	X	X	X	X	X	X
following vehicle		X	X	X	X		X	X	X	X		
oncoming traffic		X	X	X	X			X	X		X	X
vehicle in adjacent lane		X	X	X	X		X	X	X	X	X	X
merging vehicle			X		X			X				
vehicle turning across subject vehicle path	(same direction)				X			X				
	(opposite direction)		X	X	X			X	X	X		X
vehicle turning into subject vehicle path	(same direction)	X	X	X	X							X
	(opposite direction)	no data										
vehicle moving across subject vehicle path (through intersection)			X	X	X					X	X	
parked vehicle			X	X								X
pedestrian				X	X				X	X		
pedalcyclist		no data										
animal				X	X			X			X	
obstacle / object in roadway			X		X							
single vehicle			X	X	X			X			X	
other			X		X							
unknown					X							

Table 2: 100-car observed behaviours - driver factors in near-crashes.

Description Conflict with		Wilful behaviour	aggressive driving	none	Driver impairments	angry	drowsy, sleepy, fatigued	none	other emotional	unknown	Driver proficiency error	driving proficiency error	none	Inattention to forward road	none	secondary task	driving related inattention
lead vehicle			X	X		X	X	X	X	X		X	X		X	(data in separate table)	(data in separate table)
following vehicle			X	X		X	X	X	X	X		X	X		X		
oncoming traffic			X	X			X	X		X		X	X		X		
vehicle in adjacent lane			X	X		X	X	X		X		X	X		X		
merging vehicle			X	X		X		X					X				
vehicle turning across subject vehicle path	(same direction)			X			X	X				X					
	(opposite direction)		X	X			X	X		X		X	X		X		
vehicle turning into subject vehicle path	(same direction)		X	X		X	X	X		X		X	X		X		
	(opposite direction)	no data															
vehicle moving across subject vehicle path (through intersection)			X	X				X		X		X	X		X		
parked vehicle				X				X		X			X		X		
pedestrian			X	X		X		X		X		X	X		X		
pedalcyclist		no data															
animal				X			X	X		X			X		X		
obstacle / object in roadway			X	X				X		X		X	X		X		
single vehicle			X	X			X	X	X	X		X	X		X		
other			X	X				X				X	X				
unknown				X						X		X					

Table 3: 100-car observed behaviours - secondary tasks in near-crashes (3 tables).

Conflict with / Description		**Daydreaming**	looked but did not see	lost in thought	**Passenger related task**	child in rear seat	passenger in adjacent seat	passenger in rear seat	talking/singing	**Internal not vehicle related task**	insect in vehicle	moving object in vehicle	object in vehicle - other	reaching for object (not cell phone)	reading	writing - other
lead vehicle			X	X		X	X		X			X	X	X	X	X
following vehicle							X				X					X
oncoming traffic							X		X						X	
vehicle in adjacent lane							X	X	X					X	X	X
merging vehicle																
vehicle turning across subject vehicle path	**(same direction)**															
	(opposite direction)						X		X							
vehicle turning into subject vehicle path	**(same direction)**						X								X	X
	(opposite direction)	no data														
vehicle moving across subject vehicle path (through intersection)							X		X					X		
parked vehicle																
pedestrian							X									
pedalcyclist		no data														
animal							X									
obstacle / object in roadway							X									
single vehicle				X			X		X				X	X	X	
other																
unknown																

Conflict with	**Description**	**Wireless devices**	cell phone - other	dialing hand held cell phone	locating/reaching/answering cell ph.	talking /listening	**Vehicle related task**	adjusting other devices in vehicle	adjusting radio	inserting / retrieving CD	**External distraction**	looking at a pedestrian	looking at an object	looking at previous crash/incident	other external distraction
lead vehicle			X	X	X	X			X					X	X
following vehicle				X	X	X			X						
oncoming traffic						X							X		
vehicle in adjacent lane				X		X									
merging vehicle															
vehicle turning across subject vehicle path	**(same direction)**														
	(opposite direction)					X			X						
vehicle turning into subject vehicle path	**(same direction)**														
	(opposite direction)	no data													
vehicle moving across subject vehicle path (through intersection)						X									
parked vehicle												X			
pedestrian			X												
pedalcyclist		no data													
animal						X									
obstacle / object in roadway															
single vehicle			X	X		X		X	X	X					X
other															
unknown															

Conflict with		Dining	drinking from open container	eating	eating without utensils	Personal hygiene	applying makeup	combing or fixing hair	other personal hygene	Smoking	smoking cigar / cigarette
lead vehicle			X		X		X		X		
following vehicle					X		X		X		
oncoming traffic											X
vehicle in adjacent lane				X				X			
merging vehicle											
vehicle turning across subject vehicle path	**(same direction)**										
	(opposite direction)										
vehicle turning into subject vehicle path	**(same direction)**										
	(opposite direction)	no data									
vehicle moving across subject vehicle path (through intersection)					X						
parked vehicle											
pedestrian											
pedalcyclist		no data									
animal											
obstacle / object in roadway					X						
single vehicle					X				X		
other											
unknown											

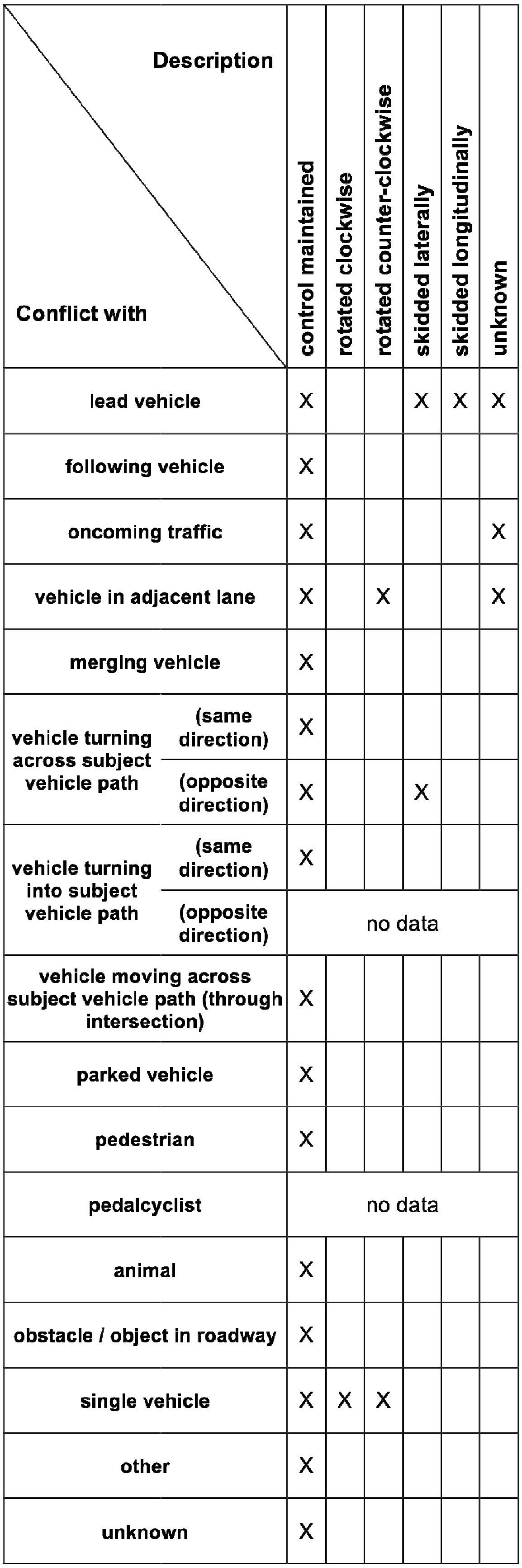
Table 4: 100-car observed behaviours - driving related inattention in near-crashes.

Conflict with / Description		center mirror	left mirror	left window	right mirror	right window
lead vehicle		X	X	X	X	X
following vehicle		X		X		
oncoming traffic						
vehicle in adjacent lane		X		X		X
merging vehicle						
vehicle turning across subject vehicle path	(same direction)					
	(opposite direction)			X		X
vehicle turning into subject vehicle path	(same direction)			X		
	(opposite direction)	no data				
vehicle moving across subject vehicle path (through intersection)			X			X
parked vehicle						
pedestrian				X		
pedalcyclist		no data				
animal						
obstacle / object in roadway						
single vehicle				X		
other						
unknown				X		

Table 5: 100-car observed behaviours - avoidance manoeuvres in near-crashes.

Description Conflict with		accelerated	accelerated and steered left	accelerated and steered right	braked and steered left	braked and steered right	braking (lockup unknown)	braking (lockup)	braking (no lockup)	no reaction	other actions	steered to left	steered to right
lead vehicle			X	X	X	X	X	X	X			X	X
following vehicle		X		X	X	X	X		X	X			X
oncoming traffic					X	X			X	X			X
vehicle in adjacent lane				X	X	X	X		X	X		X	X
merging vehicle					X				X				
vehicle turning across subject vehicle path	(same direction)								X				X
	(opposite direction)		X		X	X	X	X	X			X	X
vehicle turning into subject vehicle path	(same direction)				X	X			X			X	X
	(opposite direction)	no data											
vehicle moving across subject vehicle path (through intersection)					X	X	X	X	X	X			
parked vehicle					X				X			X	
pedestrian					X		X		X			X	
pedalcyclist		no data											
animal							X		X				
obstacle / object in roadway					X	X			X				
single vehicle					X	X				X	X	X	X
other									X		X		
unknown						X							

Table 6: 100-car observed behaviours - post-avoidance manoeuvres in near-crashes.



Description Conflict with		control maintained	rotated clockwise	rotated counter-clockwise	skidded laterally	skidded longitudinally	unknown
lead vehicle		X			X	X	X
following vehicle		X					
oncoming traffic		X					X
vehicle in adjacent lane		X		X			X
merging vehicle		X					
vehicle turning across subject vehicle path	(same direction)	X					
	(opposite direction)	X			X		
vehicle turning into subject vehicle path	(same direction)	X					
	(opposite direction)	no data					
vehicle moving across subject vehicle path (through intersection)		X					
parked vehicle		X					
pedestrian		X					
pedalcyclist		no data					
animal		X					
obstacle / object in roadway		X					
single vehicle		X	X	X			
other		X					
unknown		X					

4.2. FESTA

As FESTA did not involve an actual study no behaviours were observed.

4.3. Driver distraction in commercial operations

The behaviours observed in this study were distraction-related and included the following that the driver engaged in prior to the occurrence of a critical incident ([28]).

Task	Definition	Task Category	Manual / Visual Complexity
Dial cell phone	Driver dials a cell phone. This may also include answering the phone or hanging up the phone, if the driver presses a key during this time. Assumes driver is looking at and may reach for object.	Tertiary Task	Complex
Interact with/look at dispatching device	Driver interacts with or looks at a dispatching device. The driver usually keeps the device on the passenger seat or on the floor between the two seats and holds the device on his/her lap or steering wheel while in use. Assumes driver is looking at and may reach for object.	Tertiary Task	Complex
Look at map	Driver reads a map which is visible in the driver's hands, on the driver's lap, on the driver's steering wheel, or on the passenger seat. Assumes driver is looking at and may reach for object.	Tertiary Task	Complex
Other—Complex	Driver is engaging in an other complex task	Tertiary Task	Complex
Read book, newspaper, paperwork, etc.	Driver reads a book, newspaper, paperwork, etc, which is visible in the driver's hands, on the driver's lap, on the driver's steering wheel, or on the passenger seat. Assumes driver is looking at and may reach for object.	Tertiary Task	Complex
Text message on cell phone	Driver appears to be text messaging using a cell phone. Driver is focusing on the cell phone for an extended amount of time while continuously pressing keys. Assumes driver is looking at and may reach for object.	Tertiary Task	Complex
Use calculator	Driver uses hand-held calculator. Assumes driver is looking at and may reach for object.	Tertiary Task	Complex
Write on pad, notebook, etc.	Driver writes on some kind of paper which is visible in the driver's hands, on the driver's lap, on the driver's steering wheel, or on the passenger seat. Assumes driver is looking at and may reach for object.	Tertiary Task	Complex

Task	Definition	Task Category	Manual / Visual Complexity
Eating	Driver eats with or without a utensil (i.e., fork or spoon). This also includes the driver opening a food bag or anything closely related to eating just prior to or after the trigger. Assumes driver is looking at and may reach for object.	Tertiary Task	Moderate
Look at outside vehicle, animal, object	Driver looks outside the vehicle to another vehicle. May be out the front windshield or side window. Must be apparent that driver is focused on outside vehicle.	Tertiary Task	Moderate
Look back in Sleeper Berth	Driver turns body to look behind him/her into the Sleeper Berth.	Tertiary Task	Moderate
Other—moderate	Driver is engaging in a other moderate task	Tertiary Task	Moderate
Personal grooming	Driver is grooming him/herself. This may include combing/fixing hair, applying make-up, shaving, and brushing teeth. Assumes driver is looking at and may reach for object.	Tertiary Task	Moderate
Reach for object in vehicle	Driver may or may not remove attention from the forward roadway to reach for an object inside the vehicle. Objects may include, but are not limited to, cell phone, CB, food, drink, map, paperwork. This option should only be marked if the driver is not engaging in any other behavior at the same time.	Tertiary Task	Moderate
Smoking-related behavior—reaching, lighting, extinguishing	Driver is reaching (ashing), lighting, or extinguishing a cigarette. May include behaviors such as driver reaching for a lighter or reaching for a pack of cigarettes. Assumes driver is looking at and may reach for object.	Tertiary Task	Moderate
Talk or listen to CB radio	Driver talks or listens to a CB radio. Assumes driver is looking at and may reach for object.	Tertiary Task	Moderate
Talk or listen to hand-held phone	Driver holds a hand-held phone to ear, appears to be talking and/or listening.	Tertiary Task	Moderate
Talk or listen to hands-free phone	Driver talks or listens to a hands-free phone. This is apparent by an earpiece in the driver's ear.	Tertiary Task	Moderate
Use/reach for other device	Driver reaches for or uses an alternate electronic device. Assumes driver is looking at and may reach for object.	Tertiary Task	Moderate

Task	**Definition**	**Task Category**	**Manual / Visual Complexity**
Adjust instrument panel	Driver is adjusting something on the instrument panel. This may include, radio, climate controls, head lights, and other switches to the front and right of the driver. Assumes driver is reaching for and/or looking at the instrument panel while adjusting.	Tertiary Task	Simple
Bite nails/cuticles	Driver is biting nails and/or cuticles. Assumes driver is looking at hands.	Tertiary Task	Simple
Drink from a container	Driver drinks from a container. This also includes the driver opening/closing a drink container or anything closely related to drinking just prior to or after the trigger. Assumes driver is looking at and may reach for object.	Tertiary Task	Simple
Interact with or look at other occupant(s)	Driver is talking to a passenger sitting in the passenger's seat or in the sleeper berth that can be identified by the person encroaching into the camera view or the driver is clearly looking and talking to the passenger.	Tertiary Task	Simple
Other—simple	Driver is engaging in a other simple task	Tertiary Task	Simple
Other personal hygiene	Driver is conducting some kind of other personal hygiene. This may include rubbing eyes/face, scratching face/neck, or picking nose.	Tertiary Task	Simple
Put on/remove/adjust hat	Driver puts on, removes, or adjusts his/her hat. Assumes driver is looking at and may reach for object.	Tertiary Task	Simple
Put on/remove/adjust seat belt	Driver puts on, removes, or adjusts his/her seat belt. Assumes driver is looking at and may reach for object.	Tertiary Task	Simple
Put on/remove/adjust sunglasses or reading glasses	Driver puts on, removes, or adjusts his/her sunglasses. Assumes driver is looking at and may reach for object.	Tertiary Task	Simple
Remove/adjust jewelry	Driver is removing or adjusting jewelry. This may include, watch, bracelet, necklace or earrings. Assumes driver is looking at and may reach for object.	Tertiary Task	Simple
Smoking-related behavior—cigarette in hand or mouth	Driver has a cigarette in hand or mouth.	Tertiary Task	Simple

Task	Definition	Task Category	Manual / Visual Complexity
Talk/sing/dance with no indication of passenger	Driver appears to be vocalizing either to an unknown passenger, to self, or singing to the radio. Also, in this category are instances where the driver exhibits dancing behavior or is whistling.	Tertiary Task	Simple
Use chewing tobacco	Driver is using chewing tobacco. This may include putting tobacco into mouth or spitting into container. Assumes driver is looking at and may reach for object.	Tertiary Task	Simple
Check speedometer	Driver glances directly down to the speedometer. Must be apparent that the driver is looking at the speedometer and not in lap.	Secondary Task	N/A
Look at left-side mirror/out left window	Driver looks at the left-side mirror or out the left window for a driving-related reason (i.e., checking traffic before a lane change or turn).	Secondary Task	N/A
Look at right-side mirror/out left window	Driver looks at the right-side mirror or out the right window for a driving-related reason (i.e., checking traffic before a lane change or turn).	Secondary Task	N/A

In addition to recording the above behaviours, eye glance analysis was conducted for all safety-critical events and baseline epochs – for 5 s prior to the onset of the safety-critical event and for 1 s after. This analysis was done to measure inattention. The following eye glance locations were identified and analysed from the recorded video data (Olsen et al., p. 30):

- Forward
- Right mirror/out right window.
- Left mirror/out left window.
- External object—through front windshield.
- Instrument panel (including speedometer, radio and heating, ventilating, and air conditioning-HVAC).
- Cell phone.
- Interior object (e.g., food/drink, map, seatbelt, door/window control, CB radio, passenger, etc.).
- Eyes closed (eyes had to be closed for at least 5 syncs; 10 syncs = 1 s).
- Other.
- No eyes visible—glance location unknown.
- No eyes visible—eyes are off road.

4.4. Other studies

The AAA study [16] looked at behaviours that involved driver distraction and their potential effect. Hence, the behaviours that were observed involved driver distracting activities – namely:

- talking on the telephone,
- eating/drinking,
- music/audio,
- smoking,
- reading/writing,
- grooming,
- occupant distraction,
- internal distraction, and
- external distraction,

In addition, the study focussed on consequent driver behaviours involving driver attention when looking at the driving environment, driver not paying attention on the driving task by looking inside the vehicle, lane swerving, entering another lane and sudden braking.

In [17] the focus of the different studies that were summarised was on the evaluation of new technologies such as ABS, cruise control and crash warning systems. Hence, depending on the tested system different behaviours were sought. Examples include the effect of a lateral drift warning on driver safety and the effects of secondary behaviours on driving performance.

5. Data collection Tools

In this section, a review of the used or suggested data acquisition systems and sensors is presented. Although the requirements of cars and trucks and the constraints for installation differ from those of a PTW, the literature was useful as a pre-screening of the available possibilities.

5.1. 100-Car Naturalistic Driving Study

In the 100-car study ([3], [19], [20]) a specifically designed data acquisition system (DAS) was used. The system consisted of a Pentium-based PC104 computer that received and stored data from a network of sensors distributed around the vehicle. Data were recorded on the system’s hard drive, which could store several weeks of driving data before it needed to be downloaded. Each of the sensing subsystems within the vehicle was independent, so that any failures were limited to a single subsystem. The subsystems were (Figure 2):

- a box to obtain data from the vehicle network;
- an accelerometer box for longitudinal and lateral acceleration;
- two systems to provide information on distance respectively to lead and following vehicles (EATON VORAD EVT300 Doppler radar, 180 degrees of span, 9.14 m maximum distance);
- a system to detect conflicts with vehicles to either side of the subject vehicle;
- a GPS data module;
- ACN to trigger a call to a dispatcher in case of accident;
- cellular communication;
- an incident box to allow drivers to flag incidents for the research team;
- a video-based lane tracking system to measure lane keeping behaviour;
- system initialization;

- video to validate any sensor-based findings.

The functions of the single modules are summarized in Table 7.

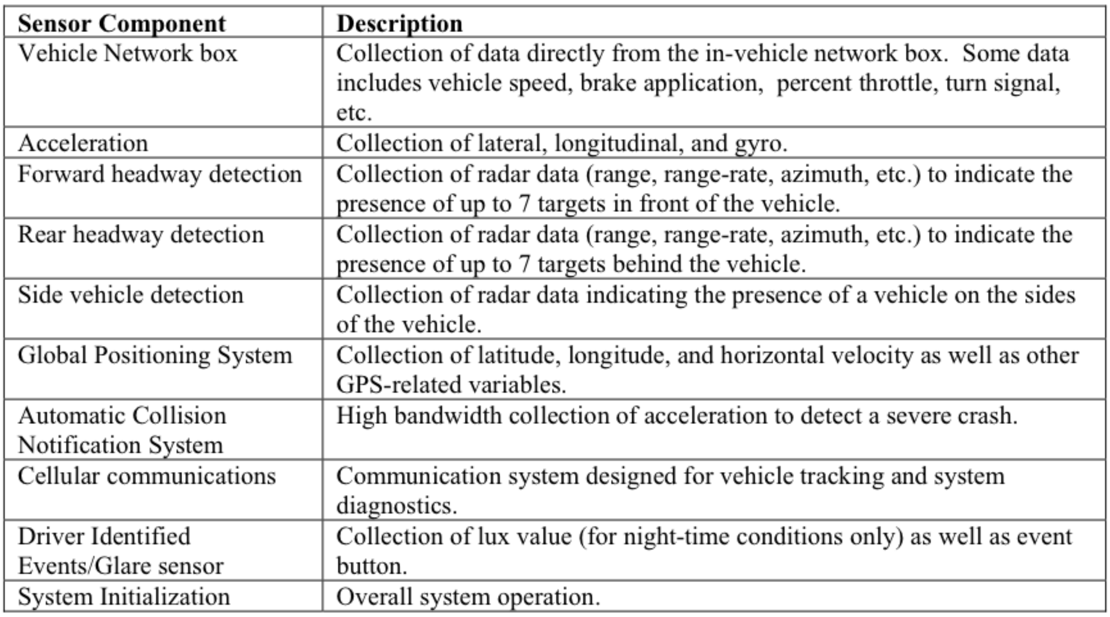
In the video sub-system five channels of digital video were implemented: driver's face and driver side of the vehicle, forward view, rear view, passenger side of vehicle, and over-the-shoulder view for the driver's hands and surrounding areas (Figure 3). All video cameras had a field of view between 60 and 70 degrees.

Video channels were composed in a single frame and compressed with the MPEG1 algorithm (Figure 2). Videos were originally recorded at 30Hz, but the compression algorithm reduced the frequency of unique frames to approximately 7.5Hz.

The cellular communications sub-system allowed the experimenters to determine the system status and position, while the system initialization equipment was used for an automatic control of the system status.

The DAS used in this study purposefully contained a large number of sensors, some of which were redundant, with the goals of maximizing the level of redundancy within the system and obtaining a dataset that represented a nearly best-case scenario of data availability. This large number of sensors may not be needed for a larger-scale study.

Table 7: Description of subsystems functions ([20]).



Sensor Component	Description
Vehicle Network box	Collection of data directly from the in-vehicle network box. Some data includes vehicle speed, brake application, percent throttle, turn signal, etc.
Acceleration	Collection of lateral, longitudinal, and gyro.
Forward headway detection	Collection of radar data (range, range-rate, azimuth, etc.) to indicate the presence of up to 7 targets in front of the vehicle.
Rear headway detection	Collection of radar data (range, range-rate, azimuth, etc.) to indicate the presence of up to 7 targets behind the vehicle.
Side vehicle detection	Collection of radar data indicating the presence of a vehicle on the sides of the vehicle.
Global Positioning System	Collection of latitude, longitude, and horizontal velocity as well as other GPS-related variables.
Automatic Collision Notification System	High bandwidth collection of acceleration to detect a severe crash.
Cellular communications	Communication system designed for vehicle tracking and system diagnostics.
Driver Identified Events/Glare sensor	Collection of lux value (for night-time conditions only) as well as event button.
System Initialization	Overall system operation.

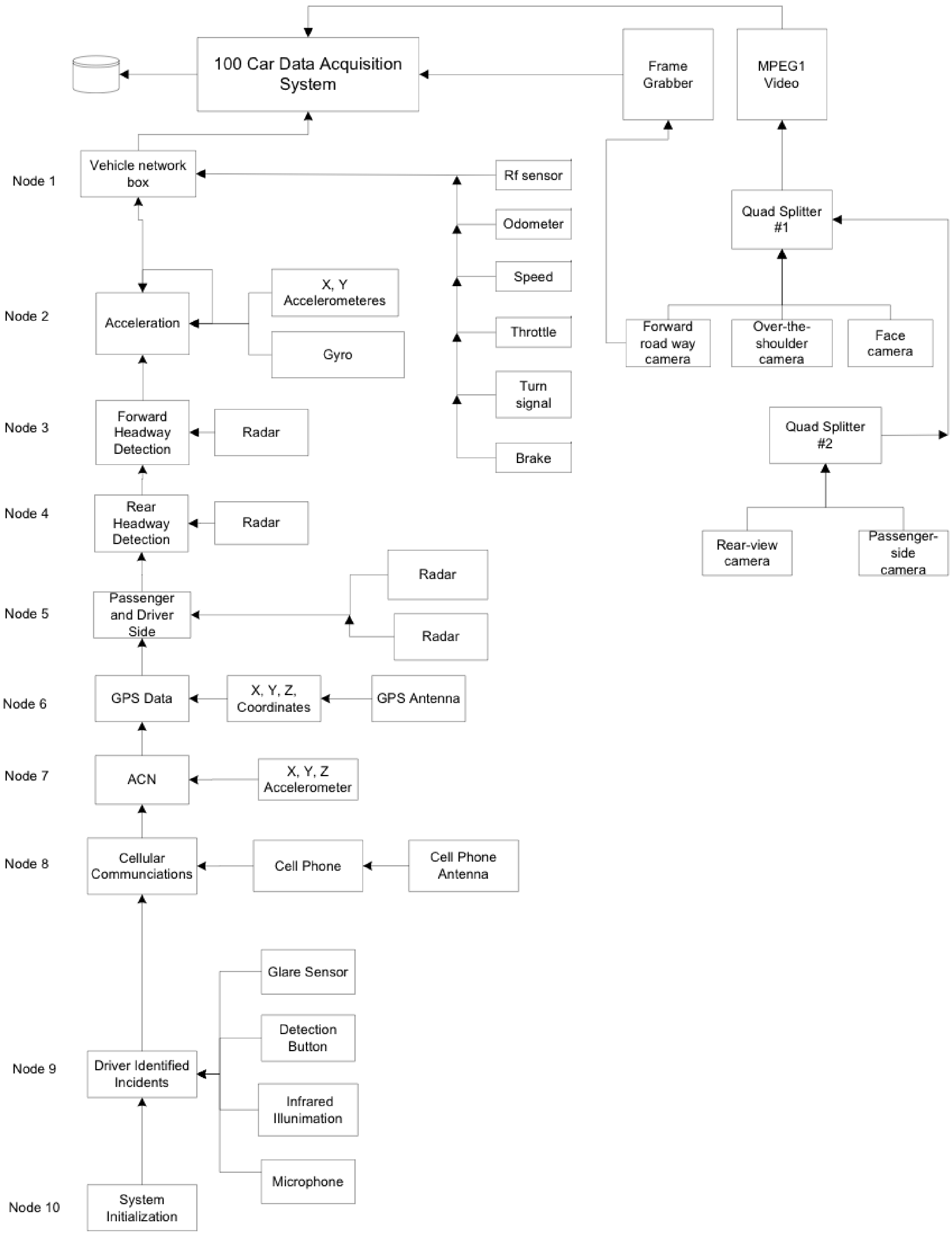


Figure 2: Structure of the Data Acquisition System used in the 100-Car Naturalistic Driving Study ([20]).

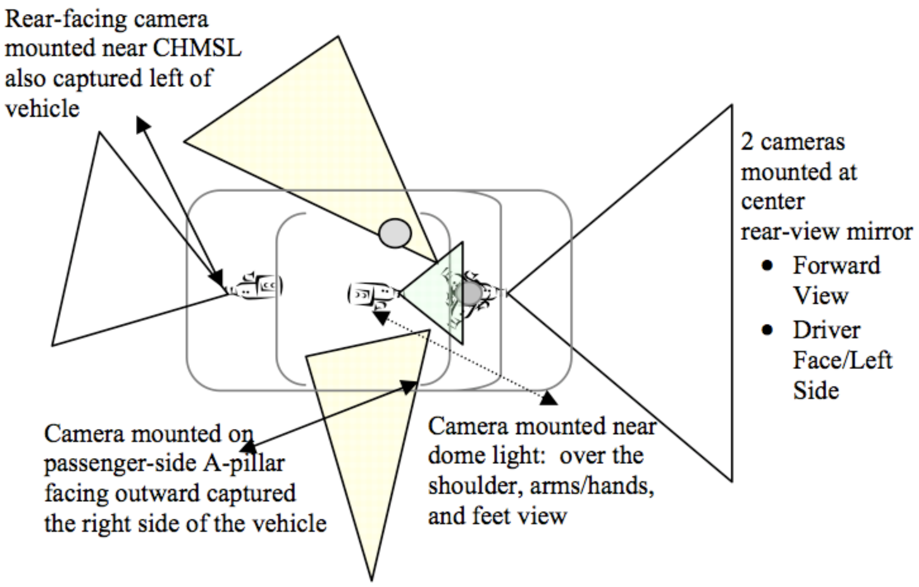


Figure 3: Camera positions and views inside the vehicles of the 100-Car study ([20])

5.2. FESTA

Within the FESTA project [8] many different methods of data acquisition were discussed, including methods and tools for collecting different kinds of background data (i.e.data involving driver, system, vehicle and road environment characteristics which are independent of system use elements), digitally acquired data from different types of sensors, and subjective data.

The background data needs to be collected and integrated during the driver interaction procedure. Due to privacy issues part of the background data may not be suitable for storage in a database, while other data can be stored and used directly in statistical as well as other forms of analyses. The driver background data may include variables describing demographic, physical and cognitive, driver experience or driving style characteristics and should be collected prior to the actual driving. These can be collected by means of interviews and/or questionnaires, and laboratory tests, (e.g. performance tests).

The digitally acquired data from different types of sensors involve on-vehicle Data Acquisition Systems. An on-vehicle Data Acquisition System (DAS) is needed to collect information about the driver interaction with the vehicle and the surroundings. Special care must be taken on the mechanical and electrical requirements of the systems. On-vehicle DAS types include fixed on-vehicle DAS with limited wireless transfer, fixed on-vehicle DAS with full wireless transfer as well as Nomadic Device (ND) based DAS with full wireless transfer. NDs could be part of the function/system under test or it could be part of the data acquisition systems. When there is not a high demand on video resolution or image refresh rate, NDs can also be used as tools to store data. Nomadic devices can also be used as sensors by a dedicated data logging software running on the device itself. With specific software the ND could also be used to: detect vehicle position compared with road lane, detect distance from preceding vehicle, detect traffic signals, and detect level of traffic.

Subjective data acquisition includes data acquired in a range of ways; e.g. via interviews and questionnaires. This could be more beneficial if not used at the same time with the field test, but rather before and after, so as not to influence driver behaviour. Questionnaires and interview information are usually collected by experimenters directly. Questionnaires can also be distributed by post or realized as a web-based survey. One drawback with postal and web based questionnaires is the level of controllability, of the sample characteristics, as the response rate will not be 100% and, hence, the driver sample characteristics are not able to be controlled.

Real time observation is data collected by an observer that directly or indirectly is observing the drivers and systems to be evaluated. Direct observation refers to a situation when a person, the observer, is present in the vehicle while collecting data (with the observer in the vehicle, there is always the risk of the driver not acting the way he or she would otherwise). Indirect observation refers to a situation when the observer observes and analyses video-recording of driver behaviour etc. Data includes information on actions, reactions, interactions and compensating behaviors of which the individual is not aware.

The acquisition of infrastructure and other service data includes environmental data (e.g. temperature, weather), traffic status (from radar or loops) and visibility range. In some countries it is required to contact the local authorities before installation of equipment close to the road. Services include all kinds of information gathered by an external source (non subject vehicle) and transmitted to the subject vehicle for some reason (for example real time traffic flow information and information about dynamic speed limits).

The acquisition of vehicle parameters is achieved by one or several internal vehicle networks such as CAN, LIN (Local Interconnect Network), MOST (Media Oriented Systems Transport) or the upcoming FlexRay. An internal network may carry large amounts of useful information such as steering wheel motion, pedal usage, vehicle speed, turn indicator as well as system-specific data from adaptive cruise control and frontal radar. The on-vehicle video provides the analyst with information about the context of both driver behavioural aspects and the interaction with the environment (if external video is used). Using an interlaced camera/capturing technology (used in PAL and NTSC standards) will produce vertical image jittering effects when capturing a moving scene. Without proper and effective de-interlacing, at compression this effect can produce a blurred image. The use of progressive (non-interlaced) scan cameras (digital or analogue) and hardware during the complete video capture chain is thus preferable. Moreover, due to storage limitations, compression or limitation of captured video is necessary. The compression could be done in both hardware and software.

Automatic in-vehicle driver monitoring could also be accomplished by using eye or head-trackers in the vehicles. The problem with the trackers is that there might be/will be significant data dropouts due to limitations in driver head and gaze tracking.

Adding sensors that the driver has to put on and wear should be avoided to assure as natural a driver behaviour as possible. Moreover, the continuous recording of audio is considered a significant privacy issue, and the driver must be informed appropriately and provide consent on the use of the data prior to the experiment.

Sometimes it is required to acquire more data that are not available on vehicle bus systems. This could be achieved either by an analogue/digital IO device or by radar and other non-video environmental sensing. Examples of extra analogue/digital data sources are: temperature sensors, vehicle battery voltage, and driver push buttons. For drivers who wish to make comments on specific events during driving, an annotation/comment button and a microphone can be provided.

5.3. Driver distraction in commercial operations

The dataset for the study was derived from two earlier studies the DDWS FOT and the NTDS.

DDWS FOT:

The main data collection tools were the DAS, the vehicle network (like a passenger car CAN bus), an Incident Box and video cameras.

DAS. The DAS was described as follows (Olsen et al., 2009, p. 18): "The DAS computer received and stored data from a network of sensors distributed around the vehicle. The DAS consisted of five major components: an encased unit that housed the computer and external hard drive, dynamic sensors, vehicle network, incident box, and video cameras. In addition, the DAS interfaced with the DDWS and recorded data from it. Each component was active when the vehicle ignition system was turned on. The system remained active and recorded data as long as the engine was on and the vehicle was in motion. The system shut down in an orderly manner when the ignition was turned off. The system paused if the vehicle ceased motion for 10 min or longer."

Vehicle Network. Parameters collected from the Vehicle Network included vehicle speed, distance since vehicle start-up, ignition signal, throttle position, and brake pressure (no more information was provided). In addition to the truck network measures, other driver input measures that were collected with sensors included right and left turn-signal use, and headlight status (on/off). An interface was developed to access the data from the vehicle network and merge it with the DAS data set (Olsen et al, 2009).

Incident Box: The Incident Box contained a light meter that recorded the in-cab ambient illumination level and an incident pushbutton which participants were instructed to push when they were involved in a safety-critical event. When pushed, the button opened an audio channel for 30 s during which the driver could comment on what had happened (Olsen et al, 2009).

Video Cameras: Four digital video cameras were used to continuously record the driver and the driving environment. The cameras were multiplexed into a single image. There were 4 camera views: forward, driver's face, rear-facing-left, and rear-facing-right (Olsen et al, 2009). There was no audio track in the video data stream. The only audio data collected was from the Incident Pushbutton.

NTDS:

The data collection tools for the NTDS study were almost identical to those for the *DDWS FOT*. The main differences were the inclusion of one additional camera view (looking over the drivers' shoulder into their lap), the absence of a driver drowsiness warning system and inclusion of a lane tracker.

5.4. Other studies

In [16] the data acquisition system was comprised of a camera unit, camera cable, recording unit and trigger cable. The instrumentation that was selected had to be unobtrusive, because of the location it was placed in respect to the driver. It was installed in the vehicles of the volunteers for a period of approximately one week.

In [17] the equipment used within the framework of the different studies consisted of a main computer, a video computer, ruggedized disks and the power controller. A variety of data transfer techniques was used. More specifically, these included:

- Wireless remote techniques (cellular transfer of summary data and remote system diagnostics)
- Wireless site-based (Wi-Fi based data transfer to stations, and high-speed networking)
- On-board storage, which was considered to be the cheapest and most reliable technique but not the most convenient

6. Procedures and methods

The scope of this chapter is to collect procedures and methods used in other NDSs and FOTs in order to:

- trigger appropriate consideration of these topics in the design stage of a NRS to avoid the omission of important actions;
- provide a basis for the application of the procedures and/or methods to a NRS.

The are several main areas of focus: drivers, equipment, data management (i.e. collection, download, and storage), data analysis (i.e reduction and processing) and general aspects related to quality control.

6.1. Subject recruitment

6.1.1. 100-Car Naturalistic Driving Study

One of the main goals of the 100-car study ([3], [19], [20]) was to record as many crash and near-crash events as possible. Participants were selected based upon an average mileage of approximately 27.000 miles per year, make/model of vehicle they drive, and gender. This was facilitated by selecting subjects with higher than average crash- or near-crash risk exposure. As the sample was meant to include subjects with crash or near-crash risk exposure above average, a larger sample of drivers below 25 years of age was selected as well as a sample with higher than average mileage driven per year. In the planning phase of the study the target was to recruit people as follows:

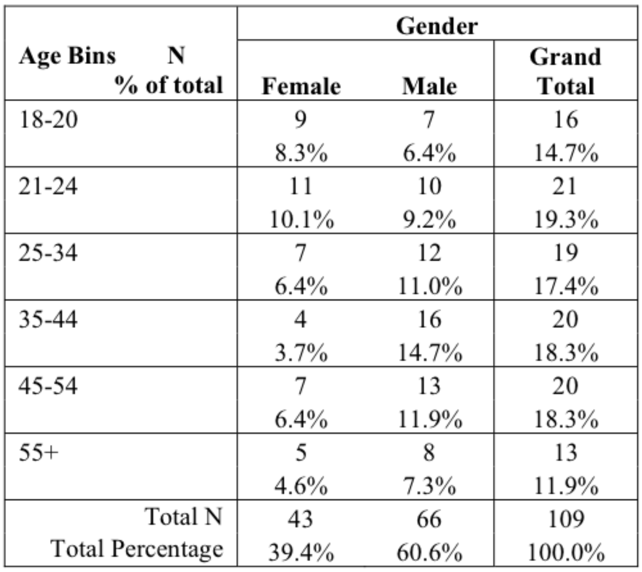
- Aged 18-20 years: drivers = 18 males and 12 females
- Aged 21-24 years: drivers = 18 males and 12 females
- Aged 25-34 years: drivers = 6 males and 4 females
- Aged 35-44 years: drivers = 6 males and 4 females
- Aged 45-54 years: drivers = 6 males and 4 females
- Aged 55-64 years: drivers = 6 males and 4 females

From the selection process extreme drivers in either direction (i.e., very safe or very unsafe) were excluded. The selection process was based also on the information of self-reported traffic violation and crashes. Gender was more or less balanced across all age groups. The age and gender distribution of the primary drivers is reported in Table 8.

109 primary drivers where recruited by flyers on vehicles and newspaper announcement (nine drivers were removed from the study): 78 of the participants drove their own vehicle whereas 22 drove leased study-vehicles. Due to the fact that the vehicle was also driven by family members and friends, 132 additional drivers have been registered. Data collection was restricted to one area, mainly characterized by urban and suburban driving conditions with moderate to heavy traffic. Consequently the sample was not representative within the US.

These parameters of the recruitment are important to consider when it comes to generalizing the results obtained with the sample to a population.

Table 8: Age and gender distribution of primary drivers [20].



Age Bins N % of total	Gender		
	Female	Male	Grand Total
18-20	9 8.3%	7 6.4%	16 14.7%
21-24	11 10.1%	10 9.2%	21 19.3%
25-34	7 6.4%	12 11.0%	19 17.4%
35-44	4 3.7%	16 14.7%	20 18.3%
45-54	7 6.4%	13 11.9%	20 18.3%
55+	5 4.6%	8 7.3%	13 11.9%
Total N Total Percentage	43 39.4%	66 60.6%	109 100.0%

6.1.2. FESTA

Some general considerations arise from the FESTA project [12]. Depending upon the research questions, there is often a need to select a particular group of participants. The types of variables that should be taken into account include: demographic variables, driving experience and personality and attitudes. The first two variables are relatively easy to measure using questionnaires. Personality and attitudes, however, deserve more attention as there are a number of different ways in which one can evaluate them. During subject recruitment, it is inevitable that there will be a progressive shrinking of the research participant population. It may therefore be necessary to screen a large number of drivers in order to recruit a relatively small number of participants with the appropriate characteristics.

More specifically FESTA [9] focused on:

- *participant demographics*: they are often defined by age, gender, income, disabilities, mobility, educational attainment, home ownership, employment status and location. They can be generally classified in the following categories:
  - permanent variables (age, gender);
  - socioeconomic variables (income, education, employment and marital status);
  - permanent driver impairment;
  - temporary driver impairment.
- *driving experience*: when conducting a FOT, it is important to take into account the driving experience of the participants, especially when the FOT includes intelligent vehicle systems. The main issues are:
  - overall driving experience;
  - experience with various systems;
  - accident history;
  - time of the day and road type.
- *personality and attitudes*:
  - influence of personality and attitudes on driving behaviour

Given the large body of literature that has sought to associate personality dimensions and attitudes with aberrant driving behaviours, many FOTs incorporate a battery of psychometric measures. Such measures are generally included in order to relate psychological factors to driving behaviour, rather than select participants per se, but when testing certain intelligent transport systems there may be some benefit in basing recruitment on personality and attitudes ([9]; p. 4-6).

- selecting participants

  Pre-screening participants according to a personality trait/attitude using psychometric instruments will allow the researcher to ensure that a range of drivers with the desired characteristics are included within the FOT. Finding participants who score near the extremes of measures, however, is likely to be difficult and, unlike other screening criteria such as age or gender, there is no easy way to identify ‘high sensation seekers’ or ‘externals’.

- *FOT Sample size and power analysis*: FOT studies should be able to assess the functionality of the system and its impact on the driver, traffic safety etc. When the chosen sample size is too small, statistically proving the effects of the system is more difficult. With very large sample sizes the chance of finding an effect is increased. However, there are two major drawbacks on just using large sample sizes; first every driver/participant needs a car equipped with the system and with a data logging system, which is expensive and second, we might find very small effects to be statistically significant, but probably not relevant.

  The appropriate sample size for a FOT depends on a number of choices that have to be made in the final set-up. These are, for instance, the number of systems that are going to be tested and the choice of a between (each participant takes part in only one experimental or control condition) or a within (each participant encounters every level of treatment or experiences all experimental manipulation) subject design.

6.1.3. Driver distraction in commercial operations

The dataset for the study was derived from two earlier studies the DDWS FOT and the NTDS.

The DDWS FOT data were collected from 103 drivers; 24 drivers were randomly assigned to a Control group and 79 drivers were randomly assigned to an Experimental group. Each driver drove for around 60 h in a 7-day period. About 48,000 driving-data hours covering 2.4 million miles travelled were collected. Forty-six trucks were instrumented with a data acquisition system (DAS) and a drowsy driver warning system (DDWS). Drivers mainly rotate into an instrumented truck, and each drove, on average, for 12 weeks (Olsen et al., 2009).

The NTDS data were collected from 100 drivers from 4 participating companies. Ninety five were male drivers and five were female. Each driver drove for around 45 h in a 7-day period. Around 14,500 driving-data hours covering 735,000 miles travelled were collected. Nine trucks were instrumented with a data acquisition system (DAS). Each truck was driven by 6–14 different drivers for approximately 4 weeks each.

6.1.4. Other studies

Bonnard and Brusque [14] stated that the definition and representativeness of the drivers’ sample is of crucial importance for generalization of results. Various relevant patterns of the population have to be taken into account when selecting the participants. Thus, the sample should be controlled with regard to numbers of km driven, road networks taken and travel purposes, as well as driver characteristics. Nevertheless, a correction of exposure data will always be necessary to extend accurately the results to the entire population.

As an example, the study of naturalistic lane changes by Lee, Olsen and Wierville [1] was comprised of a sample of 16 commuters driving more than 40 km in each direction. Half of the subjects commuted on an interstate route and half on a US highway. This selection helped to guarantee the collection of a high number of lane changes within a relatively short period of time (a total of 8.667 lane changes, each participant driving for ten days) and thus to be able to answer the research questions this study focussed on. The sample consisted of an equal number of sedan drivers and of SUV drivers. Subjects were aged between 20 and 64 (M=40.8, SD=12.2), with an equal gender representation.

Knowledge of the factors that pre-dispose PTW riders to significantly increased risk may be useful in screening out certain riders, or for including certain riders, in the NRS sample. In [5] the findings of a case-control study of motorcycle riders are reported. The cases comprised 222 motorcycle crashes occurring on public roads in the Melbourne metropolitan area from November 1995 to January 1997 in which the rider or pillion was taken to hospital or died. The controls were 1195 motorcyclist trips which passed the crash site at the same time of day and day of week as the crash occurred. Rider characteristics which were associated with statistically significantly increased crash risk were:

- age under 25 (compared with age 35 or over)
- never married
- unlicensed
- experienced off-road rider before gaining on-road license
- having fewer years of on-road riding experience (after adjustment for BAC)
- rode less than 3 days per week
- having completed a beginner course compared with an advanced course
- BAC>.05 (odds ratio of 38) - 13% of crashed riders for whom BAC was known had BAC>.05 compared with less than 1% of control riders
- BAC>.00 (odds ratio of 5)
- consumed alcohol in the previous 12 hours (odds ratio of 2)
- not wearing a helmet (2% of crashed riders and 1% of controls)

In [16] subjects were recruited primarily through advertisements published in local papers. In addition flyers were posted to recruit specific subpopulations (e.g. at a local senior centre to recruit older drivers), as well as a limited direct mailing to potential study participants was also used. In few cases, subjects heard about the study from their co-workers or friends. Potential study participants were screened via a brief telephone interview. The primary requirements for participants were that they had a valid driving license, were driving at least six hours per week, and were driving a vehicle that had rear seat access into the trunk (through which the camera and trigger cables would pass). They also had to be willing to visit the research offices to have the equipment installed and return a week later to have it removed. The number of participants was 70 (35 for each of the two locations: one involving a more rural and interstate driving environment and the second one involving a more urban and suburban environment) and included 14 participants in each of the five age groups: 18-29, 30-39, 40-49, 50-59 and 60+. There were equal numbers of males and females in each age group.

6.2. Subject briefing and training

6.2.1. 100-Car Naturalistic Driving Study

The procedure used in the 100-car study ([3], [19], [20]) included a meeting with a VTTI researcher, who ([20], p.17):

- obtained informed consent from the private vehicle or leased vehicle participant, and explained that a Certificate of Confidentiality had been obtained from the National Institute of Mental Health for the participant’s protection;
- explained that the study was investigating traffic in northern Virginia;
- explained the logistics of data collection system installation and maintenance;
- asked the participant to agree to a vision and hearing exam;
- asked the participant to complete questionnaires and take two computer-based tests.

Fifteen tests/questionnaires were used in the research:

- 13 had to be completed before data collection;
- 1 had to be completed after data collection (debriefing questionnaire);
- 1 was used only in case of a crash.

The list of tests/questionnaires, included their objectives is reported in Table 9.

6.2.2. Test Site Sweden FOT

At the beginning of the study, in the Test Site Sweden FOT [18], participants were given a consent form informing them about the aim of the study, the nature of data collection, their voluntary participation and the possibility to quit the study. Participants could choose if they wanted to allow the presentation of pictures showing their face outside the project. After this, they were given the instruction to drive as usual and the use of the incident button was explained to them. Before starting data collection, participants filled in an initial questionnaire about sex, age, living place, time of driving license, miles driven last year and total mileage.

6.2.3. Other studies

In [16], when participants visited the premises to have the equipment installed, they were first required to read and sign a consent form, which mainly described the purpose of the study, what was requested within the framework of the study (e.g. for how many days the experiment was taking place), the amount of money paid to them and the questionnaires that they had to fill in before and after the experiment. The true purpose of the study was not disclosed to the participants, but it was stated that the objective was to learn “how traffic and roadway conditions affect driving behaviour”. Consequently the participants were only instructed to “drive normally”. Moreover, they were also asked to complete a brief survey form involving their general characteristics and their driving habits. When subjects returned to have the equipment removed from their vehicles, they were given a second brief questionnaire survey to complete that included more detailed questions about their driving habits and their reactions to having the equipment in their vehicle.

6.3. Equipment installation

6.3.1. 100-Car Naturalistic Driving Study

In the 100-car study ([3], [19], [20]) the DAS unit was mounted under the package shelf (behind rear seat for SUVs). The Doppler radar antennas were mounted behind special plastic license plates in front and rear of the vehicle. Furthermore, a component was mounted above and in front of the centre rear-view mirror which included an incident pushbutton box and miniature camera (behind a “smoked” Plexiglas cover). The forward-view camera and the glare sensor were located behind the centre mirror.

Table 9: Tests and questionnaires used in 100-Car Study [20].

Test/Questionnaire	Test Type	When Administered	Brief Description
1. Visual Acuity Test	Performance test using verbal report	Before data collection	Used the Snellen Eye Chart to test driver's visual acuity.
2. Audiogram Air Conduction Test	Examination using an audiometer	Before data collection	Assessed hearing levels at a frequency range of 125-8000 Hz.
3. Medical Health Assessment	Questionnaire	Before data collection	Obtained any information on prior health problems that may relate to driving performance.
4. Walter Reed Army Institute of Research Preliminary Sleep Questionnaire	Questionnaire	Before data collection	Measured and recorded subject's sleep habits and problems that may cause drowsiness.
5. Dula Dangerous Driving Index	Questionnaire	Before data collection	Classified driver's level of aggressive driving behavior.
6. Driver Stress Inventory	Questionnaire	Before data collection	Used a 10-point Likert Scale to obtain information about driver's general attitudes toward driving on a variety of roadways and in traffic congestion.
7. Life Stress Inventory	Questionnaire	Before and after data collection	Obtained information about the types of stress and changes that the subject may have experienced in the past year to determine the risk level for illness.
8. NEO FFI (Neuroticism Extraversion Openness Five Factor Model)	Questionnaire	Before data collection	Measured the five dimensions of normal personality: neuroticism; extraversion; openness; agreeableness; and conscientiousness.
9. Way Point	PC-based performance test	Before data collection	Used to identify drivers who may be at high risk for crashes by measuring their information processing speed and aptitude for vigilance.
10. Useful Field of View (UFOV)	PC-based performance test	Before data collection	Used to measure a driver's risk for crash involvement by using the driver's central vision and processing speed, divided attention, and selective attention.
11. Debriefing Questionnaire	Questionnaire	After data collection	List of questions collecting information on driver's recollections about events that occurred during the last year, seat belt use, alcohol use, etc.
12. Driver Demographic Information	Questionnaire	Before data collection	List of questions collecting information on driver's age, gender, level of education, occupation, etc.
13. Driving History	Questionnaire	Before data collection	List of questions collecting information on driver's traffic violations and accident history, type, etc.
14. Post-Crash Interview Form	Interview questionnaire	In the event of a crash	Used to collect driver's description of crash
15. Seatbelt	Questionnaire	Before data collection	Assessed seatbelt use and attitudes toward seatbelt use.

6.3.2. FESTA

In the FESTA project [8] an installation specification document was prepared to guide the installation procedure for FOTs. The most important topics involved were:

- Mounting: positioning, means of attachment, accessibility, safety and security
- Cabling: dimensions, shielding, drawing, mounting, tolerance and labelling,
- Connectors: soldering/pressing, robustness, impotence and labelling to avoid mix up,
- Power supply: consumption, fuse, voltage, source and switching, and
- Environmental endurance: effects on electromagnetic disturbances, temperature, humidity, vibration, shock, electric safety and dirt.

The actual installation and dismounting work needs to be done by operators that are authorized to work on the actual host system, e.g. road authority authorized personnel for roadside installations and authorized vehicle mechanics for vehicle installations. When the system is installed it needs to be verified and calibrated before the data acquisition starts. Specifically, if there are other systems that could be affected by the installation, all interferences need to be monitored to verify that no conflicts can be generated. To ensure data validity and quality a calibration and verification scheme is recommended.

6.3.3. Other studies

In [16] guidelines for the installation and operating of the equipment in the vehicles were produced to be given to the drivers. However, the equipment was installed in the drivers' vehicles by the people carrying out the survey; a procedure which lasted approximately 30 minutes. The camera unit was mounted inside the vehicle just below the vehicle's rear view mirror and it primarily comprised two miniature cabin cameras, a miniature road camera, and a microphone. One of the two cabin cameras was focused on the driver's face, whilst the second one captured a wider-angle view of the vehicle's interior. The road camera was directed outside at the roadway immediately in front of the vehicle. Both the cameras and the microphone were hidden from the driver's view by near-infrared filters that covered openings on both sides of the camera box. After the end of the experiment, the equipment was removed by the people carrying out the experiment; a procedure which lasted approximately 15 minutes.

6.4. Data collection

6.4.1. 100-Car Naturalistic Driving Study

The procedure used in the 100-car study ([3], [19], [20]) included periodical remote checks of the DAS thorough the cellular communication subsystem module in order to reduce data loss due to the failure of sensors or a subsystem. Failure rates were analyzed at the end of the data collection period. Failures were divided in two groups:

- major and catastrophic failures resulting in significant data loss (all channels lost); and
- minor failures, including the loss of a single data channel.

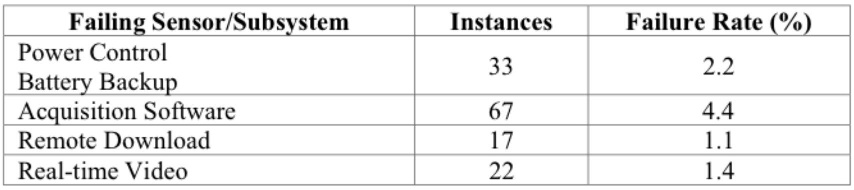
Catastrophic and major failure rates per sensor or subsystem are shown in Table 10. Sensors and subsystems not mentioned in the table did not exhibit any catastrophic or major failures. Minor failure rate are reported in Table 11. In some cases, when minor failures occurred, the data could still be used in data reduction because a redundant source of data was available. The failure rates were calculated based on the time required to detect a failure (~1 week) and estimates for the time to perform a repair (~2 weeks).

Most of the sensors used in the data collection effort had very low failure rates, which will likely be even lower as technology progresses. The most problem-prone sensors were video and radar. Given the advantages of video, however, it seems that its place as a sensor in a larger-scale study is necessary, although a smaller number of cameras might be acceptable.

The failure rate for radar was lower than for video. The radar units have to be carefully installed and they are usually damaged in crashes. The relative position and speed of leading traffic are important factors to consider for triggering to obtain valid events. Thus, despite the failure rate, the technology would be needed for a larger-scale study. Of course, if other technologies could sense the same data with a lower failure rate, they should be considered. However, as stated in the report, at the time of the study no such technology existed at a reasonable price.

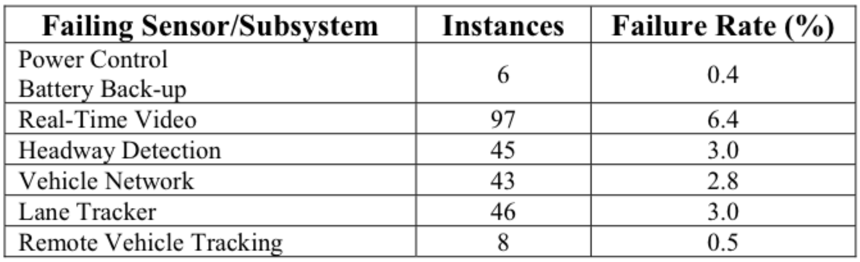
Other sensors, including accelerometers and gyroscopes (for yaw rate), had negligible failure rates, undetectable for the current study. These sensors also provided data that proved very useful for valid event discrimination. These sensors should be included in the sensor suite for a large-scale study.

Table 10: Catastrophic or major failure rates by sensor or subsystem [20].



Failing Sensor/Subsystem	Instances	Failure Rate (%)
Power Control Battery Backup	33	2.2
Acquisition Software	67	4.4
Remote Download	17	1.1
Real-time Video	22	1.4

Table 11: Minor failure rates by sensor or subsystem [20].



Failing Sensor/Subsystem	Instances	Failure Rate (%)
Power Control Battery Back-up	6	0.4
Real-Time Video	97	6.4
Headway Detection	45	3.0
Vehicle Network	43	2.8
Lane Tracker	46	3.0
Remote Vehicle Tracking	8	0.5

6.4.2. Other studies

Bonnard and Brusque [14] emphasize the importance of suitable processes aiming at guaranteeing the quality and consistency of the collected data. Therefore, the robustness and simplicity of the data acquisition system has to be assured, preventing hardware and software failures. Moreover additional processes aimed at detecting possible breakdowns should be applied. These include a repetitive remote monitoring of technical equipments functioning, e.g. through information automatically sent out by the system via wireless connection. The servicing processes need to be reactive and mobile. Data loss should be prevented through periodical partial data downloads (preferably using a wireless connection).

The authors also recommend implementing communication strategies for keeping a connection with the vehicle outside network coverage.

6.5. Data download and storage

6.5.1. 100-Car Naturalistic Driving Study

In [3], [19], and [20] the position of the vehicles was monitored remotely using cellular communication and GPS data. The personnel drove to the location of the instrumented vehicle and downloaded the data from the experimental vehicle (downloading required a data transfer cable connected to an outlet near the rear license plate of the instrumented vehicle, which was connected to a data storage device). After each download, data integrity was verified. The remote monitoring of the vehicle and the installation position of the data outlet allowed the procedure to be carried out without the presence of the driver.

Afterwards data were duplicated on DVDs and stored in separate places. At VTTI the triggering software was run on the downloaded data set and the resulting relevant event epochs were saved. Event epochs were copied and saved on the NAS server, while the remainder of the video and raw data contained on the DVD remained on the DVD. Only after this procedure the data were deleted from the from the experimental vehicle hard drive using in-house software. The purpose of this detailed duplication and storage scheme was to maintain a minimum of two data copies at all times.

6.5.2. FESTA

In the FESTA project [8] a data retrieval procedure was derived. It aimed at ensuring that all data collected in the vehicles during experiments are conveniently backed-up and stored in a safe place without any data loss. The procedure has four main goals:

- To assure that a copy of the data collected in the vehicle is stored in a safe location (Data Transfer),
- To prevent data loss by having multiple copies of the data collected in the vehicle stored in different safe places (Data Back-up),
- To verify that no data loss occurred in the copying process (Data Verification), and
- To ensure that storage space is newly available in the vehicle once the recorded data has been safely transferred, backed-up, and verified (Vehicle Data Deletion).

6.5.3. Test Site Sweden FOT

In the Test Site Sweden FOT [18], vehicle data was stored on a USB hard drive that was replaced and brought to the database in order to upload data. New software was developed for data upload: a generic interface which was able to match different formats of data and different database structures. Video data was uploaded separately from the rest of the data, in order to enable rapid direct access later on. The driver ID and personal parameters were entered manually and data was reduced to a frequency of 10Hz. The data were stored in a database which consisted of different tables (time slotted for continuous data and transitional for data with few changes). The same hardware was used for video data (binaries) and database tables, though maintaining virtually separate systems.

6.6. Data reduction

6.6.1. 100-Car Naturalistic Driving Study

Neale, Klauer, Guo and Ramsey [13] refer to data reduction as the process of selecting events of interests out of the data stream by setting post-hoc triggers. Those triggers can be single criteria or combinations of them, which may indicate the occurrence of a potentially safety-critical event. In the 100-car study, the trigger variables were lateral acceleration, longitudinal acceleration, event button activation, forward time-to-collision, rear time to collision and yaw rate. The corresponding trigger values are detailed in Table 12. After having identified the potentially relevant events, data reductionists viewed the epochs and determined the details of the event. Furthermore, they assessed the severity of each identified event.

The reductionist went through training procedures, before they gave their subjective judgement on the video and driving data. Inter- and intra-rater reliability have been calculated (Kappa statistic, tetrachoric correlation coefficient).

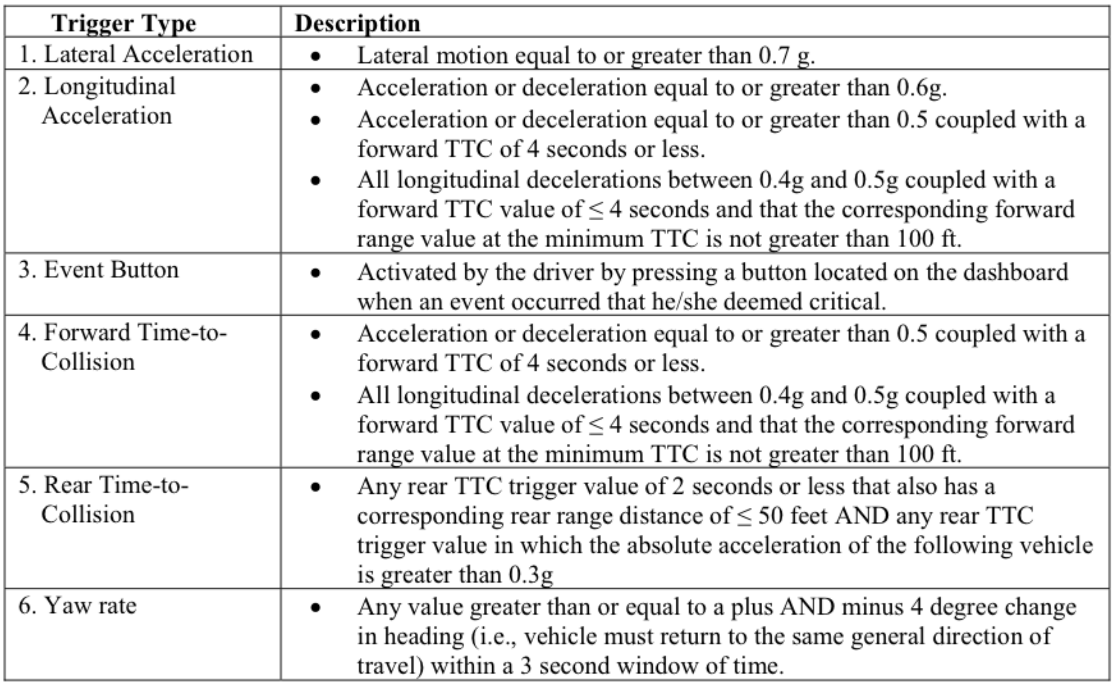
In the 100-car naturalistic study ([3], [19], [20]) three event categories were established. The classification was based on the subjective assessment of reviewers as well as kinematic and proximity data. The three types of safety-relevant events were:

- crashes, defined as “any contact between the subject vehicle and another vehicle, fixed object, pedestrian, cyclist, animal” ([3] , p.5];
- near-crashes which are described as a “conflict situation requiring a rapid, severe evasive manoeuvre to avoid a crash”;
- incidents which are “conflict[s] requiring an evasive manoeuvre, but of lesser magnitude than a near-crash”.

The raw data were processed automatically in order to detect relevant events for the purpose of the research. The definition of the triggering was performed not only for data reduction but also in order to verify the possibility to identify near-crashes only based on quantitative information derived from performance data. As stated in chapter 4, the latter objective cannot be obtained and a qualitative human analysis is necessary. Nonetheless a triggering criterion can be used, integrated with video data verification (Table 12). A similar reduction process is still inexpensive relative to the overall collection effort of a large-scale field test. From a large-scale naturalistic study perspective, crash detection is reasonably straightforward since there is often a greater than 1.0 g peak deceleration when a crash occurs. The detection of near-crash cases is more problematic. However, depending on the size of the study, it may be reasonable to make an a priori decision to capture in the range of 70 percent of 25.000 or 30.000 near-crash events if the false alarm rate can be reduced to around 10 percent. Even with a higher false alarm rate, the cost of each false alarm would be fairly low given data reduction tools similar to those used in the 100-Car Naturalistic Driving Study. The performance of triggers could be improved with the definition of driver tailored thresholds, especially when it is combined with appropriately selected expected probabilities ([20], p.LVIII).

The complete view of the data reduction process is shown in Figure 4.

Table 12: Trigger signals and thresholds used in 100-Car Study [13], [20].



Trigger Type	Description
1. Lateral Acceleration	• Lateral motion equal to or greater than 0.7 g.
2. Longitudinal Acceleration	• Acceleration or deceleration equal to or greater than 0.6g. • Acceleration or deceleration equal to or greater than 0.5 coupled with a forward TTC of 4 seconds or less. • All longitudinal decelerations between 0.4g and 0.5g coupled with a forward TTC value of ≤ 4 seconds and that the corresponding forward range value at the minimum TTC is not greater than 100 ft.
3. Event Button	• Activated by the driver by pressing a button located on the dashboard when an event occurred that he/she deemed critical.
4. Forward Time-to-Collision	• Acceleration or deceleration equal to or greater than 0.5 coupled with a forward TTC of 4 seconds or less. • All longitudinal decelerations between 0.4g and 0.5g coupled with a forward TTC value of ≤ 4 seconds and that the corresponding forward range value at the minimum TTC is not greater than 100 ft.
5. Rear Time-to-Collision	• Any rear TTC trigger value of 2 seconds or less that also has a corresponding rear range distance of ≤ 50 feet AND any rear TTC trigger value in which the absolute acceleration of the following vehicle is greater than 0.3g
6. Yaw rate	• Any value greater than or equal to a plus AND minus 4 degree change in heading (i.e., vehicle must return to the same general direction of travel) within a 3 second window of time.

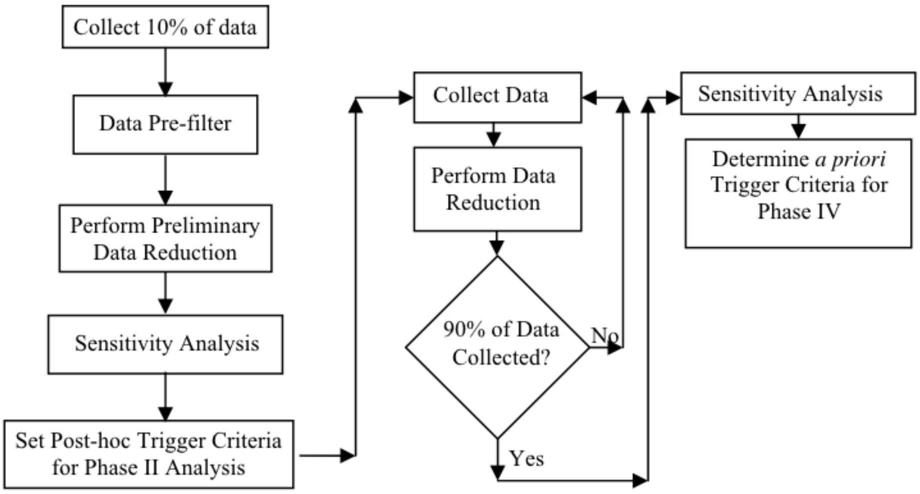


Figure 4: Data reduction process (phase II is the 100-Car Field Test and phase IV the future large scale field study).

For the latter study, a trained reductionist was able to distinguish between valid and invalid conflicts at the rate of about 50 per hour using video data. After triggers were set, each reductionist watched 90-second epochs for each event (one minute prior to and 30 seconds after). Eye glance reduction was performed for crash and near-crash events only.

The variables recorded were selected based upon past instrumented vehicle studies ([22], [23]), national crash databases (GES and FARS), and questions on Virginia State Police Accident Reports. Using this technique, the reduced database can be used to directly compare crash data from GES and FARS to those crashes, near-crashes and incidents (crash-relevant conflicts and proximity conflicts) identified in this dataset. The full set of variables recorded during the reduction process is in [20], appendix B.

In the study reported by Neale, Klauer, Guo and Ramsey [13], the reductionists also recorded environmental variables which could have contributed to the relevant event. These were weather, light, surface condition, traffic density, relation to junction, traffic flow, traffic control, alignment and infrastructure. The codification options are listed in the appendix A of the report.

In addition to the event database a baseline database was created [13], including about 20.000 segments of 6-seconds duration randomly selected for each vehicle. The proportion baseline epochs per vehicle was stratified according to the vehicle's involvement in safety-relevant events. In that way, the percentage of involvement in events for one vehicle corresponded to the percentage of its contribution to the baseline database. Thus, a vehicle not involved in any event, is not represented in the baseline data.

Event database and baseline database form a case-control dataset which allows the calculation of odds ratios (e.g.), as used by Klauer et al. [21] and Neale, Klauer, Guo and Ramsey [13].

6.6.2. Driver distraction in commercial operations

After the data were collected, trained data analysts identified safety-critical events (i.e., crashes, near-crashes, and crash-relevant conflicts). To do so, the data were processed through a specialized software program to flag potential events of interest based on trigger threshold values (see right-hand column in table below; source: Olsen et al., 2009; p 26-27). The trigger threshold values were derived from the trigger values used in the earlier NTDS and DDWS FOT studies. Spurious events were removed.

Table 13: Comparison of the Trigger Values Used in the DDWS FOT Phase I Analysis, NTDS, and the current study [28].

Trigger Type	Trigger Values Used in Phase I of the DDWS FOT	Trigger Values Used in the NTDS	Trigger Values Used in the Current Study
Longitudinal Acceleration	Deceleration greater than or equal to -0.35 *g*. Speed greater than or equal to 15 mi/h. Deceleration greater than or equal to -0.5 *g*. Speed less than or equal to 15 mi/h.	Deceleration greater than or equal to -0.20 *g*. Speed greater than or equal to 1 mi/h (1.6 km/h).	Deceleration greater than or equal to -0.20 *g*. Speed greater than or equal to 1 mi/h (1.6 km/h).

Trigger Type	Trigger Values Used in Phase I of the DDWS FOT	Trigger Values Used in the NTDS	Trigger Values Used in the Current Study
Time-to-Collision	A forward TTC value of less than or equal to 1.8 s, coupled with a range of less than or equal to 150 ft, a target speed of greater than or equal to 5 mi/h, a yaw rate of less than or equal to │4°/sec│, and an azimuth of less than or equal to │0.8°│. A forward TTC value of less than or equal to 1.8 s, coupled with an acceleration or deceleration greater than or equal to │0.35 *g*│, a forward range of less than or equal to 150 ft, a yaw rate of less than or equal to │4°/sec│, and an azimuth of less than or equal to │0.8°│.	A forward TTC value of less than or equal to 2 s, coupled with a range of less than or equal to 250 ft, a target speed of greater than or equal to 5 mi/h (8 km/h), a gyro rate of less than or equal to │6°/s│, and an azimuth of less than or equal to │0.12°│.	A forward TTC value of less than or equal to 2 s, coupled with a range of less than or equal to 250 ft, a target speed of greater than or equal to 5 mi/h (8 km/h), a gyro rate of less than or equal to │6°/s│, and an azimuth of less than or equal to │0.12°│.
Swerve	Swerve value of greater than or equal to 3 rad/s^2. Speed greater than or equal to 15 mi/h.	Swerve value of greater than or equal to 2 rad/s^2. Speed greater than or equal to 5 mi/h (8.05 km/h).	Swerve value of greater than or equal to 2 rad/s^2. Speed greater than or equal to 5 mi/h (8.05 km/h).

Each valid safety-critical event was subsequently classified as a crash, near-crash, crash-relevant conflict or unintentional lane deviation as defined below (Olson et al., 2009; p 25):

- “Crash: Any contact with an object, either moving or fixed, at any speed. Included other vehicles, roadside barriers, objects on or off of the roadway, pedestrians, pedal cyclists, or animals.
- Near-crash: Any circumstance that required a rapid, evasive manoeuvre (e.g., hard braking, steering) by the subject vehicle or any other vehicle, pedestrian, pedal cyclist, or animal, in order to avoid a crash.
- Crash-relevant conflict: Any circumstance that required a crash-avoidance response on the part of the subject vehicle, any other vehicle, pedestrian, pedal cyclist, or animal that is less severe than a rapid evasive manoeuvre (as defined above), but greater in severity than a normal manoeuvre. A crash-avoidance response can include braking, steering, accelerating, or any combination of control inputs.

Unintentional lane deviation: Any circumstance where the subject vehicle crosses over a solid lane line (e.g., onto the shoulder) where no hazard (e.g., guardrail, ditch, vehicle, etc.) is present."

6.6.3. Other studies

Bonnard and Brusque [14] mention the crucial importance of data coding accuracy for the quality of the outcomes of the study. This data coding mainly refers to video data (driver, driving environment, ongoing driving task), coded by trained researchers.

In addition to the selection by means of event triggers, Bonnard and Brusque [14] expose the possibility to select few-seconds or few-minutes periods randomly. This procedure will be used for the creation of baseline databases (a baseline database is a randomly selected stratified sample of short data segments representing normal driving - no crash, near-crash or incident).

Lee, Olsen and Wierweille [1] examined naturalistic lane changes and, therefore, adopted a different data reduction process. In a first data pass-through, lane changes where identified by video review (start and end point of each lane change) and then categorized by manoeuvre type, direction, severity, urgency and success/magnitude. Manoeuvre type had 7 categories, including slow lead vehicle, return, enter, exit and prepare to exit the roadway. Severity was rated on a 7-point scale (from unconflicted to physical contact), depending on the presence of vehicles in the proximity zone of the lane change and vehicles in the fast-approach zone. Urgency rating was done on a 4-point scale (from not urgent to critical) and depended on time-to-collision with the vehicle ahead. Success/magnitude classification included single lane changes, passing manoeuvres (within 45 s), multiple lane changes (several lane changes in the same direction) and unsuccessful, i.e. aborted, partial or unintentional, lane changes.

In a next data reduction step, a sample of 500 lane changes was selected for in-depth analysis, with an emphasis on severe and urgent lane changes. A data reduction software was developed that integrated radar, video and sensor data into a graphical display format of the events and additionally generated an event table in a spreadsheet format which included relevant lane change parameters.

6.7. Data processing

6.7.1. 100-Car Naturalistic Driving Study

In the following**, examples of analyses** performed in naturalistic studies are described. The analyses carried out vary depending on the purpose of the study.

In their study of rear-end crashes and near-crashes in the 100-car data, Lee, Llaneras, and Sudweeks [2] analysed the following variables:

- Distribution of braking response time to decelerating lead vehicle
- Failure to respond or delay in responding (break or steer)
- Relation of response and distraction of the driver (esp. improper allocation of visual attention)
- Time-to-collision (following distance and speed) at the onset of lead-vehicle breaking

- Breaking levels of decelerating lead vehicle
- Eye glance patterns compared between crashes, near-crashes and incidents
- Proportion of rear-end events involving lead vehicle stopped, mild braking, hard braking and slowing down without braking
- Distribution of types of avoidance manoeuvres
- Influences of traffic, roadway environment, ambient light and other contributing factors on the risk of rear-end events
- Distribution of locations of rear-end events

Additionally, they performed a baseline braking analysis, capturing braking events that lasted 3 s or more through a data mining software. The following analyses were included:

- Distribution of breaking levels (percentiles, number of events related to total, number related to hours of driving, number related to mileage)
- Comparison of braking levels in baseline and event data base (percentage of occurrence)
- Peak deceleration according to event severity
- Relationship between speed at start of breaking event and deceleration level
- Headway depending on baseline braking and events
- Descriptive of braking event duration
- Descriptive of times to full stop

As part of the descriptive analysis within the ITS Center project by Neale, Klauer, Guo and Ramsey [13], crashes, near-crashes and incidents identified as infrastructure-related by the reductionists were plotted on a map (Microsoft MapPoint). Relative frequencies for different infrastructure-related variables were indicated in a table, always separating crashes, near-crashes and incidents. Furthermore, the frequency of events on high-incident roadways within the study network was analyzed.

For the assessment of risk only crashes and near-crashes were used, as they show similar kinematic properties. The calculation of odds ratios within a logistic regression model was first suggested. In order to account for individual driver effects which represent a source of bias in the logistic regression approach, a Generalized Estimation Equation (GEE) model has been applied. Neale, Klauer, Guo and Ramsey [13] included eight variables into this model: weather, roadway surface condition, relationship to junction, road alignment, lighting conditions, traffic control, lane types and traffic density. The GEE model provides odds ratio estimations for the considered variables and indicates the corresponding confidence interval.

Klauer et al. [21] also made risk assessments, but concentrating on the factor of driver inattention. Performed on the 100-car study data, their analysis included:

- Calculation of relative near-crash/crash risk of different types of inattention (Odds ratios): driver engagement in secondary task, driver drowsiness, driving-related inattention to the forward roadway, non-specific eye glance away from the forward roadway.
- Calculation of population attributable risk percentage for inattention-related activity
- Prevalence of the different types of driving inattention (using a baseline distraction database)

- Analysis of survey and test battery response: relationship of driver characteristics (age, driving experience, etc.) and involvement in crashes and near-crashes
- Correlation calculated between involvement in inattention-related crashes and near-crashes and engaging in inattention-related activities during baseline driving.

Apart from these specific analyses the results of the 100-Car Naturalistic Driving Study ([3], [19], [20]) were organized in several tree structures, each one identified according to the event type (crash, near-crash and incident) and the conflict type:

- single vehicle;
- lead vehicle;
- following vehicle;
- object/obstacle;
- parked vehicle;
- animal;
- vehicle turning across subject vehicle path in opposite direction;
- adjacent vehicle;
- other;
- oncoming traffic;
- vehicle turning across subject vehicle path in same direction;
- vehicle turning into subject vehicle path in same direction;
- vehicle turning into subject vehicle path in opposite direction;
- vehicle moving across subject vehicle path through intersection;
- merging vehicle;
- pedestrian;
- pedal cyclist;
- unknown.

The factors are grouped in six categories (Figure 5):

- pre-event manoeuvre;
- precipitating factor;
- contributing factors;
    - driver factors;
    - infrastructure / driving environment factors;
    - vehicle factors;
- associated vehicle / roadway states;
    - driving environment;
    - infrastructure;
- avoidance manoeuvre;
- post avoidance manoeuvre.

The complete results of the 100-Car Study are shown in [20], Appendix C.

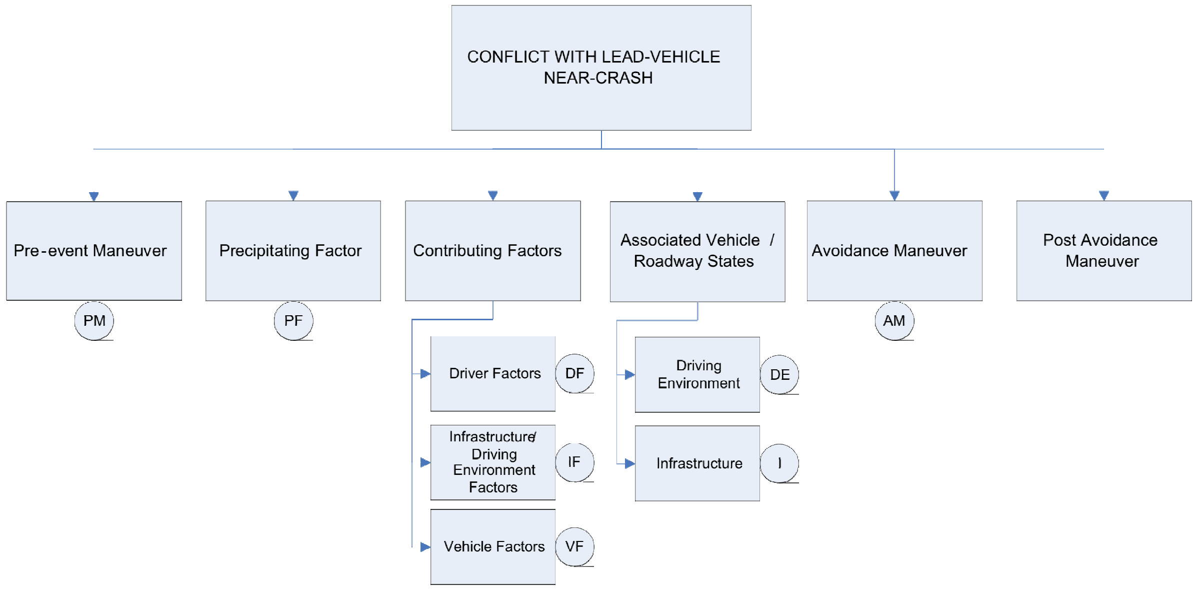


Figure 5: categories of factors defined in the 100-Car Study ([20]).

6.7.2. FESTA

The FESTA deliverable D2.4 [10] describes a bottom-up process reaching from data quality control to data processing and mining to PI calculation to testing of hypothesis and finally to a global assessment.

The monitoring of the local and global consistency of the chain of operations is especially important in order to ensure the validation of the performance indicator calculation. A control feedback loop from the top of the chain checks the evaluation process for consistency, mainly controlling the uncertainty of estimations, i.e. the models applied in the different steps of the chain. The consistency of each operation has to be checked locally according to the nature of each performance indicator (e.g. sampling rate must fit the variability of the variable, coming from driver, situation and measurement). Additionally, a global criterion that has to be met is a sample size that permits getting sufficient power to test hypotheses and make a global test with precision.

Furthermore, it is necessary to identify the different sources of variability and bias in order to minimize or control them in the data analysis. Three sources of variability are to be considered:

- **driver variation:** the accuracy of inferences depends on sample size, on the variation between drivers and the efficiency in design and analysis. A stratified sample based on some relevant factors is recommended as the best method, although for practical reasons a different selection procedure may be followed. This source of bias has to be taken into account when generalizing the results to the population.
- **driving situation variation:** the variation between and within driver journeys (traffic conditions, weather, etc.) is not controllable and therefore considered as random. An appropriate length of observation period has to be chosen which allows that the sample of driving situations covers the range of prevailing driving situations. Seasonal effects also are to be considered.

- **measurement variation:** this source of bias breaks down to inter-individual, intra-individual and infra-situational variance. In order to gain precision it has to be focussed on the concrete type of variance and appropriate measures have to be undertaken to reduce it, i.e. to compensate for great inter-individual variance it does not help to increase the number of driving situations.

Data quality analysis has to be performed before further processing the data [10]. The methods for data quality control comprise four types of checks to complement information of the data base and prepare data for analysis:

- **assessing and quantifying missing data:** a percentage of acceptable data loss has to be fixed, depending both on the total amount of data and on the identified factors that caused data loss. As an example, the Road Departure Crash Warning Field Operational Test (University of Michigan, Transportation Research Institute) set a maximum value of 5%.
- **data control:** data control means to check if the units of measure of the different data collected are reasonable and correct. Regarding the video data, the frame integrity has to be checked. Mean, max and min values of the CAN bus data have to be verified and external sensors are to be checked on plausibility. Additionally it is recommendable to check for the accuracy, resolution and frequency of those measures.
- **data dynamics check:** for each kind of measure, it has to be examined if the data dynamic over time is appropriate. Sensor data can be crosschecked with video data to assure the validity of the collected data. If video is not available, other measure can be used for the crosscheck (e.g. compare GPS with steering wheel position).
- **guarantee that measure features satisfy requirements for data analysis:** it has to be verified if the requirements needed for the specific analysis or PI calculation are met. These may refer to sample frequency, signal-to-noise ratio, time length, etc. Further requirements result from the experimental protocol, e.g. a specific age distribution or specific events, and the hypotheses and use cases to be tested (road geometry, weather conditions,…).

The same four steps apply to questionnaire data. Data loss should be quantified and it has to be checked if data is systematically missing (e.g. from one specific group of drivers). Out-of-scale values are to be excluded after data collection, while an appropriate data dynamic shall be ensured and answering tendencies avoided through a good questionnaire design and implementation.

The first three steps are general quality checks where failures may be solved through technical procedures in the database, whereas the fourth step depends on the specific analysis. A failure of the latter, therefore, may represent an intrinsic limit of the collected data but not a technical problem.

Once the data quality has been checked, data processing can start. A first step of data processing is to filter data, either using a frequency filter or an algorithm to select specific part of the data depending on hypothesis (chapter 6.6). Moreover, new signals can be derived from raw data, elaborating or combining signals according to the hypothesis to be tested. Relevant events shall be annotated by marking specific time indexes. This work might have to be done manually as a robust algorithm is challenging to write. If the evolution in time is of interest, a time scale should be defined and the data has to be reorganized accordingly.

"*The two basic types of experimental designs are within subject design (this is sometimes also referred to as crossed design) and between subject designs (this is sometimes also referred to as nested design). All FOTs (and every experimental study) need to contain a* *control condition, in which participants do not get any treatment. This condition is meant to serve as the baseline: this is how drivers behave in case there is no treatment or no experimental manipulation at all* ([9], p.13)."

In a true experiment, the experimenter has full control over as many aspects of the situation as possible e.g. the environment in which the study is conducted etc. However, in FOTs, this is not the case due to different weather types, changes in time, participant drop out etc. Experiments in which the researcher does not have full control over the situation are often referred to as quasi-experimental studies ([9], p.15]. Finally to investigate if the effect of a treatment (e.g. driving with a system) changes over time, longitudinal or cross-sectional designs should be of use ([9], p.16).

As a general rule, the results of a study should allow a clear decision if the hypothesized relationships between variables exist or not, i.e. if the hypotheses can be accepted or has to be rejected. In the best case, the researcher is able to attribute the changes he/she observed at the dependent variable without any doubts to the manipulation of the independent variable. The internal validity of an experimental or quasi-experimental study describes the extent to which this inference is unequivocally possible due to the study design. Another aspect is external validity which describes the extent to which results can be generalized to other persons, situations and points in time. The internal validity of a study increases to the extent to which such alternative explanations can be ruled out. In the literature, these factors are also described as confounding variables which need to be controlled by appropriate measures right from the beginning of a study.

The generic purpose of an FOT could be described as assessing the impact of 'system a' on 'performance b', for instance the impact of Intelligent Speed Adaptation (ISA) on driving performance. Typical sequences in an FOT would be O^x A^y and O^x A^y O^x where O represents baseline conditions and A represents the treatment condition. The superscript x and y numbers indicate, for instance, the number of weeks that the sequence will last [26] or the distance travelled [27]. In several FOTs baseline conditions have lasted for 2-3 weeks, and treatment conditions varying from 3-4 to 8-9 weeks (or longer). A 3-4 weeks treatment period may suffice but it may also be too short depending upon the overall purpose of the test (the hypothesis to be tested) and the total number of participants involved. Some research questions may require a shorter exposure/treatment while other questions require longer. If exposure is instead based on distance travelled, baseline conditions may typically prevail for 150-300 km and treatment conditions for 300 km (or more) [27].

The O^x A^y O^x design described above is typically used in order to assess the impact of a single system (or treatment). In an FOT, however, the test may not involve only the one system (or treatment) but several. One solution is evidently that different systems can be tested by different samples, providing that the samples are comparable. Different systems can also be tested by the same test participant in a sequence (cf. section on within subject design) and the FOT designed accordingly, for instance as O^x A^y O^x B^y O^x C^y O^x where A, B, and C represents three different systems (or treatments). Furthermore, an FOT may involve parallel, or integrated, testing of different systems (or treatments). Such an FOT could follow the sequence O^x A^y or O^x A^y O^x where O represents baseline conditions and A represents treatment conditions. A more complex design could involve the activation and deactivation of different systems according to predefined patterns, for instance O^x A^y O^x $(A+B)^y$ O^x B^y O^x or O^x A^y O^x B^y O^x $(A+B)^y$ O^x where O represents baseline conditions and A and B represents different systems (or treatments).

In a study involving three different technologies, Regan et al. [27] followed a similar but even more complex design. The three systems to be assessed were: Intelligent Speed Adaptation (ISA), Following Distance Warning (FDW); and Seatbelt Reminder (SBR). The design chosen involved a treatment group and a control group. The treatment participants were not exposed to all technologies for the entire length of the trial. The systems were turned on and off at predetermined points, in order to assess the effects of each system on driving behaviour before, during and after exposure. The treatment participants' trial was divided into different periods: Familiarisation, before, during, and after periods, each period determined by the distance travelled. Familiarisation meant that the drivers could become familiar with the test car; during this before period baseline performance data were collected. During the next period two of the systems (FDW and SBR) were enabled and remained so for the remainder of the study. Finally, the ISA was activated. For the remaining trial, the ISA was activated for defined periods and deactivated for other, altogether three periods on and three periods off. In this case, the researchers did draw conclusions about the individual systems and combinations of systems in terms of before ISA, during ISA, after ISA; before ISA & FDW, during ISA & FDW, after ISA & FDW; before FDW, during FDW, after FDW.

A substantial part of the analysis in FOT is the **performance indicator (PI) calculation**. The components needed for the calculation of PI are direct measures, indirect measures, events, self-reported measures and situational variables. The FESTA deliverable D2.4 [10] recommends to implement a calculation algorithm in an appropriate software, like Matlab, Excel or SPSS. It is important to develop automatic and efficient PI calculations for the large dataset; the implementation of batch processing is advisable. Data-subsets have to be selected and handled and easy procedures for manual review should be developed. Again, poor data has to be detected in order to exclude it from the analysis.

A so-called "denominator" is needed for PI calculation. This refers to exposure data that makes the measure comparable. It has to be defined how often an event occurs per "something" (time interval, distance, certain location). As there is hardly any control of test exposure in naturalistic studies, the analysis will first identify the important contextual influences and then create a "baseline" subset for comparison.

A special case of PIs are critical events. They should be identified by reviewing triggered events. Those triggers can be based on kinematics (e.g. lateral acceleration > 0.20 g, peak deceleration > 0.7 g or following interval < 0.5 s) which detect potentially critical events. True conflicts have to be selected by manual review of the video and/or by adding conditions.

In Field Operational Tests, **hypothesis testing** relies on two data samples (with and without system) from which the PI is estimated with its variance. The PIs of the two samples are compared using standard techniques (e.g. t-test), which assume that the effect is constant. A complete picture of the sources of variability, however, can be obtained by using multi-level models [24]. In order to handle possible violations of the assumption of normal distribution of the performance indicator, non-parametric tests such as the Wilcoxon rank test can be applied.

As a complementary step to hypothesis testing, **data mining** techniques can be used to reveal data patterns that have not been anticipated. This kind of exploratory data analysis can be achieved through categorising the dataset into groups (either by mean or median split for dichotomy or cluster analysis for a higher number of groups) and comparing behavioural patterns between these groups. This categorisation is normally made based on participants' characteristics, e.g. gender, age, attitude, etc.). It should be considered that one categorisation is not necessarily transferable from one data set to another due to possible differences in variation and distribution among the datasets.

To complete the analysis and interpret the results, a **global assessment** has to be finally made. Here, the first question to ask is about the representativeness of the sample for the target population. This includes controlling for the total vehicle km driven per road type and time of day.

Two types of scaling up processes can be distinguished: from sample to larger population and from performance indicators to effects (e.g. on the number of fatalities). The second one applies to FOT and is not necessarily relevant for naturalistic riding studies.

6.7.3. Test Site Sweden FOT

Regarding the **tools** required for the data analysis, the Test Site Sweden FOT [18] reports the necessity to develop tools which allow the access to data, the access to video and the visualization of data by means of an appropriate software. The tools for post-processing analysis include Matlab scripts, plots, database queries, etc. In this project, previously to data analysis, some scripts were tested (e.g. kinematic triggers detecting incidents out of heavy breaking) and some dependent measures were computed. A database search interface was designed for SQL which facilitated rapid access and provided features for advanced scripts, e.g. for evaluating trigger levels of vehicle dynamics. Moreover, a COM object was designed, in order to enable access to the database from a user-software such as Matlab, SAS or Excel.

The data analysis software included tools for selection, manipulation, display and manual annotation of collected data. Hereby, data query, video and annotation tools were handled separately from graph functions and Matlab based calculation functions (graphs were add-ons in Matlab). An interactive video and annotation tool was developed, consisting of a Graphical User Interface (GUI) with windows for viewing the video, the signal values and for adding annotations. The COM interface was used as a connection between the different applications: Matlab, video analysis software and database query software. Matlab's automation functionality was used to receive information from the playback and control it as well as the video viewer. Signals were selected and continuously updated through a Matlab GUI.

6.7.4. Driver distraction in commercial operations

Data analysis involved use of the following methods:

- Identification of safety-critical events (i.e., crashes, near-crashes, and crash-relevant conflicts) using a specialized software program to flag potential events of interest based on trigger threshold values.
- The creation of approximately 20,000 baseline epochs (i.e., uneventful driving periods of around 6 s randomly selected from the recorded data set) which were used as baseline periods. The creation of a baseline data set enabled the researchers to describe and characterize "normal" driving, and to infer the increased or decreased risk associated with various conditions and driver tasks by comparing control (baseline) data with the safety-critical event data set. "For example, if 20 percent of safety-critical events but only 10 percent of baseline epochs occurred during rain, one could infer that rain was associated with an increased safety-critical event rate, and therefore, increased risk." (Olsen et al., 2009, pp 28-29).

Statistical analyses were performed to (a) assess the increased or decreased risk associated with driver engagement in various tasks and (b) eyes off road time associated with each task. Odds ratios were calculated to "approximate relative safety-critical event risk compared to normal, baseline driving for various driver tasks." Population attributable risk (PAR) calculations were made to "determine what percentage of safety-critical events occurring in the population was attributable to driver distraction." (Olsen et al., 2009, pp 33).

6.7.5. Other studies

Constraints of the statistical analysis have to be taken into consideration in every study. As a naturalistic study has very few control (compared to "classical" experimental designs), special attention has to be paid when analysing and interpreting the data. Bonnard and Brusque [14] explain that the interpretation of statistical results has to take into account the heterogeneity of driving situations, which makes it difficult to isolate effects. Interfering variables are not controlled. The authors suggest the possibility of match-paired comparisons for each driver. In that way, each relevant situation is matched with a baseline situation, being the driver his own control. Alternatively, sequences with similar characteristics (manoeuvre, traffic condition, infrastructure, etc.) can be identified using advanced modelling such as hidden Markov modelling. Bonnard and Brusque emphasize the importance to consider the statistical approach and its constraints at an early stage of the study so that desired research outcomes can be achieved later on.

Lee, Olsen and Wierwille [1] had a closer look on naturalistic lane changes. Their data analysis included one-way and two-way distributions of lane changes as a function of severity ratings, urgency ratings and type classification. One-way and two-way distributions of lane changes were analysed as a function of gender, vehicle type, driver type and route. Moreover, analyses of variance with dependant variables duration, urgency, severity and independent variables gender, vehicle type, driver type and route were carried out. In-depth analysis was conducted using the generated event table. Apart from the above-mentioned variables, here steering, lateral acceleration, velocity, breaking, turn signal use, three measures of eye glance behaviour, distance, relative velocity and TTC to forward and rearward vehicles were included.

In this study [1], eye glance behaviour was analyzed for the three seconds prior to the event, which was found to be a critical period for lane change decision making by Mourant and Donohue [25]. Eye glance analysis has been performed separately for right and left lane changes, assuming that the detected patterns would be different.

In [16] the data processing was performed with Observer Video-Pro software, developed by Noldus Information Technology, Inc. The software was specifically developed for annotating, coding, editing and analyzing behavioural processes from video. A data coding scheme was developed for use with the Video-Pro software, which used simplistic codes to identify the analyzed parameters categories. Moreover, an operational definition table was produced to provide clear definitions of the analyzed parameters categories. Actual coding was carried out by simultaneously monitoring the three video screens (one for each one of the three cameras used) on the quad-camera monitor display and entering the respective codes. Generally at least two complete passes of the videotapes were required; the first one to code the eye direction and the hand position and the second one to code all other parameters. Three employees were needed to complete all of the coding and it must be noted that a formal inter-observer reliability check was made at several stages of the coding process.

The Observer Video-Pro software is designed to provide basic descriptive data on observational data files, but it does not provide tests of statistical significance, which were needed in this study. Hence, a major challenge was to convert the Video-Pro data to SAS data files. The initial SAS data file created was actually a file of nearly 7.5 million observations, corresponding to 207.2 hours of data coded as streams of events in 1/10 second intervals. Once the data files were finalized, the analysis approach primarily involved using the Video-Pro and SAS software to produce descriptive tabulations and cross-tabulations of the data. In addition to the video-data, the results of the pre and post surveys completed by the subjects were entered into a separate Microsoft Excel database and analyzed descriptively using SAS. Given that the longitudinal nature of the data did not meet the assumptions for classic statistical analysis methods, confidence intervals for proportions and linear combinations of proportions were constructed using the bootstrap percentile method.

Finally, in [17] three main issues were taken into account:

- How representative is the sample,
- Seasonal variations in the data, and
- Vehicle variations and their effect on system performance

6.8. Quality control

6.8.1. 100-Car Naturalistic Driving Study

The data reduction process is crucial in the 100-car naturalistic study ([3], [19], [20]). Thus a data reduction manager was appointed and was responsible for recruiting reductionists. Reductionists were:

- trained on how to access the data from the server and operate the data reduction software, and provided with training on all relevant operational and administrative procedures (approximately 4 hours of training);
- provided with a data reduction manual to guide them in learning the software and reduction procedures;
- given the possibility to practice data reduction procedures with another trained analyst prior to reducing data independently.

The training lasted 2 weeks. When they felt confident, they were authorized to work independently, with “spot check” monitoring from the project leader and other reductionists.

The data reductionists were responsible for analyzing a minimum number of events per week, and were required to attend weekly data reduction meetings to discuss issues that arose in data reduction.

To limit the subjectivity of the reductionists a protocol, implemented in a decision tree, was defined (Figure 6). In addition training procedures were implemented to improve both inter- and intra-rater reliability, and reliability testing was then conducted to measure the resulting inter- and intra-rater reliability. Specifically ([20], p.24):

- data reductionist managers performed spot checks of the reductionists’ work, monitoring both event validity judgments as well as recording all database variables;
- reductionists performed 30 minute’s worth of spot-checks of their own or other reductionists’ work every week;
- mandatory weekly meetings were held to discuss issues concerning data reduction techniques.

Verification tests proved that this approach was effective for achieving high inter- and intra-rater reliability.

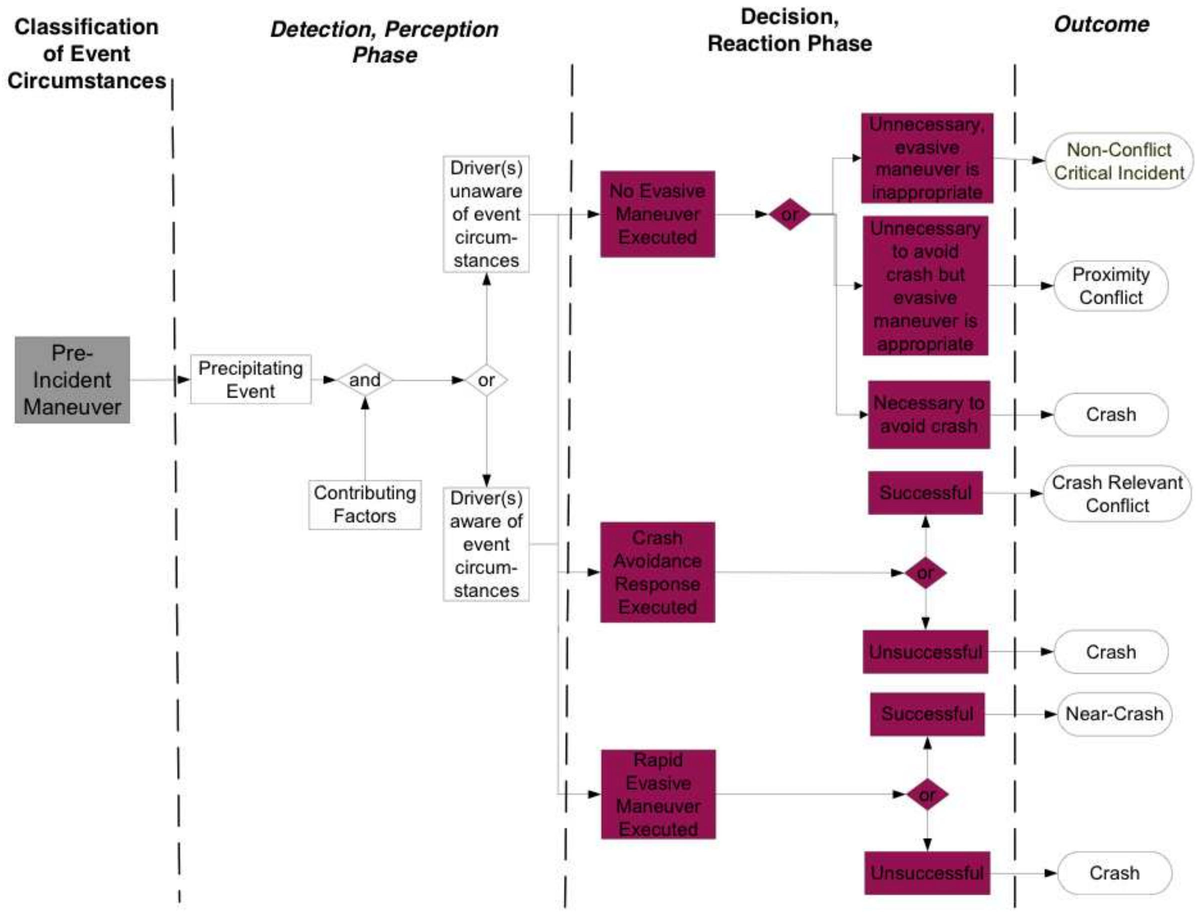


Figure 6: Event classification according to severity [20].

6.8.2. FESTA

The FESTA deliverable D2.4 [10] outlines the importance of a preliminary field test (i.e. a pilot test) in field operational tests to check the relevance and feasibility of the scientific evaluation process. Although in naturalistic driving or riding studies no ADAS or IVIS are included, the same should apply for this kind of study. The purpose of a preliminary field test is to foster the mobilisation and dialogue of involved teams, the creation of a common framework and a consensus for the evaluation process. The technical functioning of the data collection systems has to be checked in real driving situations (sensor calibration/drift, establish periodicity of maintenance procedures, validate data collection procedure).

Furthermore, the feasibility and operation of all equipment, methods and procedures has to be tested. This includes all the steps from the selection of participants through to data collection and storage. The communication process between all the partners involved in practical deployment of the study has to be checked as well as the robustness of the data collection and data transmission tools.

6.8.3. Driver distraction in commercial operations

As the study did not involve the development of vehicle systems, no testing and verification procedures were reported. However, the following are the main quality control procedures reported:

- Before the data reduction process began in the NTDS, …"a sensitivity analysis was conducted on the trigger values to determine the best combination of values to obtain the fewest number of false alarms (i.e., triggers created with no conflict threat) and missed valid events" [28]
- A 75-s epoch was created for each identified safety-critical event (60 s prior to trigger, and 15 s after trigger) that was identified using the critical event search software. The validity of all the events was determined through manual video review by researchers. Invalid events were "those events where sensor readings were spurious due to a transient spike or some other anomaly such as driving over a pothole (false positive)." [28]
- Given the large number of baseline epochs that were reduced, quality control measures were developed to ensure accurate coding among analysts. Data analysts were trained on how to code the baseline epochs using a purpose-developed "Baseline Epoch Data Directory" with categories such as "roadway surface condition" (dry, wet , ice …), and "Light Condition" (daylight, dark, dawn ..). [28]

7. Ethical and legal implementation issues

7.1. Ethical issues

When conducting a naturalistic driving study, it is of utmost importance to respect the privacy of the drivers [14]. Data protection has to be guaranteed by the experimenter. Corresponding laws have to be checked carefully, as they may differ among countries. The participants have to sign a consent form explaining that data collection will be anonymous and that they can quit the study at any time. Here, a difficulty comes up as the collection of consent forms of secondary drivers and passengers might be complicated.

Respecting personal data protection can be achieved by choosing carefully the type of parameters recorded (e.g. video without audio), but in this case constraints in the data analysis appear. Another possibility for respecting the privacy of the subjects is to allow the participants to switch off the data recording whenever they want to, informing the researcher about the reason.

The participants need to be informed in advance about [12]:

- the purpose of the FOT;
- the risks they may incur;
- the costs that are covered and not covered (and so have to be borne by them);
- whom to contact in case of breakdown, etc.

The participants, after having received the proper information about the study and personal data protection, must provide the written consent. In any case the human rights legislation must be respected, namely the Helsinki Declaration of 1964 and its subsequent revisions. This declaration enshrines the right of the individual to be informed and provide prior consent. The individual's protection and rights supersede any interests of scientific progress.

Proper data protection according to EU directive (1995) and subsequent national laws must be guaranteed. Although participants have been informed of the video recordings, the possibility that the data are passed to a third party can create problems [12].

The basics of data protection include [12]:

- protect server from intrusion;
- main database and personal ID data of drivers must be kept separate, although it must be possible to pair data and personal ID at a later stage;
- personal ID data should also be encrypted.

Different levels of data security should be implemented in order to cover personal and privacy issues properly [8]. Namely not all projects have the permission to access all of the project data. The data access right of a project partner should depend on his specific role in the project. Driver data allowing direct conclusions about the identity of the driver is considered to have highest requirements regarding data security. Access to video data needs to be controlled: e.g. by ensuring that viewing video data is only possible on-site at specific places; ensuring that access to GPS data/video data requires a certain level of data access right.

7.2. Legal implementation issues

As stated in the FESTA project deliverables [11] and [12] "*it is not possible to provide a comprehensive guide to all the legal issues that can arise in a particular FOT, as these may be very dependent on the system(s) to be tested and on the study design adopted.*" Although in naturalistic studies the focus is not on the testing of new devices/systems but rather on the data acquisition, the possibilities to instrument a PTW are unlimited and thus an exhaustive number of cases cannot be listed. In projects that involve cross-border traffic or use/preparation of vehicles in different countries, national regulations and laws must be considered also when European regulation and laws are present (e.g. data protection and privacy) since the interpretation and application can vary. For these motivations an a priori risk assessment and the support of a legal consultant is strongly advisable. In order to maximise the effects and avoid iterative cycles, this information should be available in the early stage of the project. In addition the project plan needs to clearly identify who are the persons responsible for ensuring compliance [12].

However a checklist can be created for the major topics:

- participants must have legal entitlement to drive the vehicles in question and be eligible for insurance;
- formalise the arrangement between the organisations and the participants (contract or letter of agreement);
- define what happens in the event that a participant commits a traffic offence and/or incurs a traffic penalty (speeding ticket, parking ticket, etc.);
- define who is responsible for minor damage to the vehicle and payment of any insurance excess;
- define the person(s) allowed to drive the vehicle (e.g. other household members) and under which circumstances. Only the participants will have been properly informed about their responsibilities. There is no way to ensure that any third parties are properly briefed;
- prepare a comprehensive risk assessment plan;
- assess the potential for failures to arise from modifications to and interaction with in-vehicle systems (e.g. radio and electrical interference, reducing vehicle crashworthiness, HMI designs that cause distraction);
- make the vehicle pass the Whole Vehicle Type Approval processes and comply to Construction and Use regulations, and proceed with a check of the appropriate authorities, who may be the national government or a designated approval agency.

8. Conclusions

The purpose of this document has been to review the design, methods, and implementation strategies for naturalistic driving studies that have been previously undertaken, in order to inform the design of a naturalistic riding study to be undertaken in WP 2.2 of the 2-BE-SAFE project. Several naturalistic driving studies and field operational tests were reviewed, including the major ones. Unfortunately, a naturalistic riding study involving Powered Two Wheelers currently being undertaken in the United States of America by VTTI was not reviewed since as yet there are no public deliverables deriving from it that are available. In this deliverable field operational tests were included for review since they share with naturalistic driving studies many common technologies, methodologies and procedures for data measurement and collection.

In the analysis of the cited documents it had to be considered that the naturalistic riding study performed in this project will be unique since it will be organized and performed in four different European countries, with partially different legislation, by four different research teams. Although the research teams will share a common vision and they will synchronize their actions, the organization of the study will be more complex compared to most of the studies reviewed in this document that are typically developed and run at a single site. Nonetheless the state-of-the-art reported in this document provides relevant information for the planning of the experimental activities and of the data analysis.

There are several issues of particular importance that must be taken into account in the next stage (i.e. in WP 2.2 of 2-BE-SAFE).

Utmost consideration must be given to ethical issues, with a detailed communication of the rights and duties to the persons involved in the study and an efficient protection of the data (section 7.1).

Analysis of legal issues must proceed in parallel with consideration of technical issues. Although it is impossible to have an exhaustive list of the legal implementation issues, which applies to all naturalistic studies (or FOTs), a checklist of the major topics was indentified (section 7.2) and it is suggested that teams ask for legal support within their organizations in the preparatory phase of the NDR in order to anticipate possible problems. As a specific point within legal issues, the vehicles should undergo a new approval process after the installation of sensors or, as a secondary alternative, a risk assessment should be performed and the results should be included in the document for the informed consent of the participants.

There must be clear definition of the goals of the study and cross verification with the availability of appropriate instrumentation.

There must be in-depth characterization of the subjects involved in the study. In the reviewed research this was performed with different focuses and levels of detail, but in all the major studies the following areas are taken into account: demographical data; driving experience; and personality and attitude towards driving.

A definition of a reliable and consistent set of data must be developed. In previous studies video signals have always been included (alone or in parallel with other signals), although they do not show a high reliability (section 6.4). Other signals common to the major research activities are: GPS position; accelerations; speed; pedal use (in cars); steering angle turn-signal use.

There must be a carefully defined data acquisition strategy. All previous research activities have involved continuous data acquisition with post-processing based on automatic triggers, which were set in order to provide false positive relevant events. The selected events were always reviewed by reductionists before being included in the database.

A common policy for data download and storage must be defined in order to avoid possible loss of part of the dataset. It is suggested that the safe practices reported in section 6.5 be adopted.

Implementation protocols must be developed which define univocal actions for all teams in all stages of the NRS, in particular for subject recruitment, subject briefing and data processing. Although the availability of common documents and shared practices is relevant throughout the entire research process, implementation protocols must cover these aspects in particular in order to avoid systematic biases to the study. For data processing, additional effort is necessary in order to guarantee a similar performance level for the reductionists of the different teams and thus to obtain a reliable dataset. It is suggested that a reliability check procedure be considered which is compatible with the resources available for the study.

A common database structure and coding scheme must be defined for the events of interest.

Finally, as suggested by the FESTA consortium, pilot testing of all equipment, methods and procedures is critical in order to eliminate possible problems that may not have been foreseen in the design phase of the NRS.

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