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## Revision and history chart

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Table of contents

Revision and history chart ........................................................................................................ iii
Table of contents ....................................................................................................................... iv
Executive summary .................................................................................................................... 5
euroFOT assessment methodology .......................................................................................... 5
Use of the methodology ............................................................................................................. 7
1 Introduction ............................................................................................................................. 8
  1.1 Objectives ............................................................................................................................ 9
  1.2 Scope and work process ....................................................................................................... 9
  1.3 Relations with other work packages and deliverables ......................................................... 11
  1.4 Outline deliverable and reading instructions ..................................................................... 12
2 FOT analysis methods: general set-up ................................................................................... 13
  2.1 FESTA ................................................................................................................................ 13
  2.2 Breakdown of research questions ....................................................................................... 15
  2.3 Required data .................................................................................................................... 16
  2.4 Types of effects and approaches to calculate effects .......................................................... 19
  2.5 Harmonisation of procedures and integration of results .................................................... 20
  2.6 Disentangling the effects of bundled functions ................................................................ 21
3 User-related aspects .............................................................................................................. 26
  3.1 Introduction ........................................................................................................................ 26
  3.2 Hypothesis Testing – Objective Data ............................................................................... 29
  3.3 Hypothesis Testing – Subjective Data ............................................................................... 36
4 Safety impacts ....................................................................................................................... 41
  4.1 Step 1. Defining the target crash population ................................................................... 47
  4.2 Step 2. Identifying changes in safety related measures between baseline and treatment .... 48
  4.3 Step 3. Interpreting what any identified change between baseline and treatment means in
terms of a generalized safety impact on the EU27 level .......................................................... 50
4.4 EBA example – FCW/ACC ................................................................................................. 56
  4.5 ABA examples .................................................................................................................... 60
  4.6 PRM – estimating the influence of ACC on rear-end crashes ........................................... 60
  4.7 Methodological concerns .................................................................................................. 67
5 Traffic efficiency impacts ...................................................................................................... 72
  5.1 Introduction ........................................................................................................................ 72
  5.2 Direct traffic efficiency effects – linear approach ............................................................... 77
  5.3 Direct traffic efficiency effects – modelling approach ....................................................... 81
  5.4 Indirect traffic efficiency effects ....................................................................................... 97
6 Environmental impacts .......................................................................................................... 101
  6.1 Introduction ........................................................................................................................ 101
  6.2 Direct environmental effects – linear approach ............................................................... 106
  6.3 Direct environmental effects – modelling approach ......................................................... 109
  6.4 Indirect environmental effects ....................................................................................... 112
7 Scaling up and Cost-benefit analysis .................................................................................... 114
  7.1 Need for socio-economic assessment & general methodology ....................................... 114
  7.2 Data needs & impact appraisal ........................................................................................ 114
  7.3 Scaling up ........................................................................................................................ 116
  7.4 Conclusion: Minimum set of data .................................................................................... 120
8 Discussion ............................................................................................................................... 121
  8.1 Challenges and solutions ................................................................................................. 121
  8.2 Consequences for results ............................................................................................... 123
9 References ............................................................................................................................. 125
Annex 1 Glossary ....................................................................................................................... 129
Annex 2 Hypotheses List and Worked Examples of Hypotheses Testing ................................ 131
Annex 3 Specification of situational variables ........................................................................ 166
Annex 4 Descriptions simulation models ................................................................................. 169
Executive summary

The goal of SP6 is to assess the societal and individual impacts of the Advanced Driver Assistance Systems (ADAS) that are tested in the euroFOT project. This deliverable describes the methodology for the impact assessment and evaluation of user related aspect in euroFOT. Data analysis methods are described for each of the work packages to be undertaken within SP6 of the project: User Acceptance and User-Related Aspects Evaluation (WP 6300); Impact Assessment (traffic safety, traffic efficiency and environment; WP6400) and Socio-Economic Cost Benefit Analysis (WP6500).

euroFOT investigates ADAS that are already present in the market or are mature enough to be tested as commercial functions. The following eight functions were selected:

- Longitudinal functions: Adaptive Cruise Control (ACC) and Forward Collision Warning (FCW) together in one bundle (counted as one function) and Speed Regulation System (SRS): Speed Limiter (SL) and Cruise Control (CC);
- Lateral functions: Lane Departure Warning (LDW), Impairment Warning (IW) and Blind Spot Information System (BLIS);
- Other functions: Curve Speed Warning (CSW), Fuel Efficiency Advisory (FEA) and Safe Human-Machine Interaction (SafeHMI).

These functions are being evaluated in five test sites across Europe: Sweden, Germany (two test sites), Italy and France.

The results of the data analysis activities will be described in four separate deliverables (D6.3 - D6.6), corresponding to each of the impact areas: user-related aspects, safety impacts, traffic efficiency impacts and environmental impacts. All assessment results will become available in an overall document: Deliverable 6.1 (Final evaluation results). The results of the impact assessment will be used as input for the socio-economic cost-benefit analysis, and the results of this analysis will be reported in D6.7 (Overall Cost-Benefit Study).

euroFOT assessment methodology

In the impact assessment, hypotheses will be tested and research questions will be answered. This will be done using performance indicators, situational variables and events. These hypotheses, research questions, performance indicators, situational variables and events have been defined in earlier work packages in SP2 and SP4. The impact assessment methodology is based on the approach defined in the EC-funded Field opEritional teSt supporT Action (FESTA) project, which has been adapted to the specific conditions and needs in euroFOT.

During the FOT both subjective data (derived from questionnaires and driver interviews) and objective data (derived from the vehicle CAN and video recordings) are being gathered. Data processing and data analysis are being carried out and performance indicators and situational variables are being calculated.

Assessment approaches

Different approaches are used for the assessment methods for the four impact areas.

The user-related aspects that will be assessed are driver behaviour, driver workload, driver acceptance, trust, function usage, and exposure. In this assessment both objective data and subjective data are used. The assessment involves hypothesis testing.
The purpose of the safety impact analysis is to assess the extent to which the functions being evaluated in euroFOT can be expected to alter the current crash populations at the EU level in terms of accidents, injuries and fatalities. The safety methodology has three main steps: 1) definition of the target crash population, 2) identification of changes in safety-related measures between baseline and treatment, and 3) interpretation of significant changes in terms of accidents, injuries and fatalities at the EU level.

The traffic efficiency aspects that will be assessed are travel time and accident-related congestion. The analysis will determine the impact of the euroFOT functions on travel time losses and accident-related congestion at the EU level.

For the environmental assessment, fuel consumption and CO₂ emissions will be assessed, again at the EU level.

For both the efficiency and environmental impact assessment two approaches will be used: a linear approach and a modelling approach. The linear approach uses FOT data directly and effects are scaled up to the EU level via situational variables. The modelling approach uses FOT data as input for traffic simulations and environmental models, in order to model the interaction between equipped and non-equipped vehicles at higher penetration rates than those in the FOT. The linear approach will be applied to all functions, and the modelling approach will be applied to the ACC + FCW bundle and the SL/CC bundle, where the largest interaction effects are expected.

The methodology described in this deliverable is designed specifically for euroFOT as it is based on euroFOT data and functions. However, with some adaptations, it can be applied more generally to other Field Operational Tests (FOTs).

Integration of results and debundling of effects

The eight euroFOT functions will be tested in different combinations and different configurations at five different test sites across Europe. Integrating the results as well as separating the effect of the individual functions is therefore a huge challenge. When differences occur between the measured data and results at the different test sites, it will be difficult to make a good comparison between test sites and to give one result for a function that holds for the different test sites. For a good integration of results per function, or bundle of functions, the following methodological steps are foreseen:

1. Harmonisation of procedures for hypothesis selection and testing;
2. Integration of empirical results within each test site. If there are multiple indicators for one impact area, then this step harmonizes their outcomes, even when they show different effect sizes or contradictory results;
3. Integration of empirical results between test sites. The main approach here is to combine the assessments over the test sites by making a weighted average of the results;
4. Disentangling the effects of bundled functions.

Scaling up

The results of the impact assessment will be scaled up to the EU level to serve as input for the socio-economic cost-benefit analysis. Scaling up of traffic efficiency and environmental effects is based on EU vehicle kilometres, and scaling up of safety effects is based on EU accident numbers.
Use of the methodology

The data analysis methodologies described in this deliverable, including the list of hypotheses and the subsequent analysis, match both the euroFOT ambition and the original project timelines.

At the time this deliverable was being finalised, there was discussion about a possible reduction in the scope of SP6 activities, and in the time available to complete the analysis activities. If effort and available time to complete SP6 activities is reduced, it will not be possible to test all the hypotheses specified in this deliverable, and the analysis activities undertaken may be limited.
1 Introduction

This deliverable describes the methodology for the impact assessment and evaluation of user related aspect in euroFOT. The euroFOT project is the first large-scale Field Operational Test (FOT) of multiple Advanced Driver Assistance Systems (ADAS) undertaken in Europe. It evaluates, using instrumented vehicles, the impacts of ADAS on traffic and the acceptance of ADAS to ordinary drivers in real traffic. Almost 1000 vehicles (cars and trucks) from different manufacturers and hosting different ADAS take part in the study that started in 2008.

One of the goals of SP6 of euroFOT is to analyse the user acceptance and traffic effects of ADAS that are already present in the market or are mature enough to be tested as commercial functions. Based on the recommendations on existing roadmaps and on the availability of well developed functions, the following eight functions were selected for euroFOT:

- **Longitudinal functions:** Adaptive Cruise Control (ACC) and Forward Collision Warning (FCW) together in one bundle (together counted as one function) and Speed Regulation System (SRS): Speed Limiter (SL) and Cruise Control (CC)
- **Lateral functions:** Lane Departure Warning (LDW), Impairment Warning (IW) and Blind Spot Information System (BLIS)
- **Other functions:** Curve Speed Warning (CSW), Fuel Efficiency Advisory (FEA) and Safe Human-Machine Interaction (SafeHMI)

These functions are evaluated in vehicles supplied by European manufacturers. Several data acquisition systems installed in the vehicles are used to collect a wide range of data (CAN-data, video, GPS location, etc.). The vehicles are managed and monitored from test sites across four European countries (Sweden, Germany, France and Italy): the Vehicle Management Centres (VMCs).

A detailed understanding of the user acceptance of the functions, of the impact of the functions on safety, efficiency and environment based on measurements in real traffic, and of the costs and benefits of the functions in monetary terms is gained during the project. This deliverable presents a methodology for assessing these aspects that can be used to:

- Analyse the user related aspects of the ADAS;
- Analyse effects at the EU level of the ADAS on safety, efficiency and environment at various penetration rates (low / medium / high);
- Provide input for the cost benefit analysis.

The impact assessment translates the effects found in the trips made by the equipped fleets in the FOT to the EU level. In other words, the effects found in the FOT data for certain situations or for certain groups of drivers are scaled up to both a larger population and geographical scope. This leads to an assessment of the potential effects of the evaluated ADAS were they to be widely deployed in the vehicle fleets in entire Europe.

This deliverable focuses on the methodology of the assessments: how will the assessments be carried out. This deliverable does not include results. Links between analyzing user related aspects and effects on safety, efficiency and environment are explained in the document. This deliverable is a result of SP6 (Evaluation, Impact Assessment, Socio-economic CBA) and, more specifically, of WP6300 (User Acceptance and User related Aspects Evaluation) and WP6400 (Impact Assessment).

This introductory chapter contains some more background information: objectives of the deliverable, scope and work process, relations with other work packages and deliverables, outline of the document and reading instructions.
1.1 Objectives

This document describes the methodology for assessing the user related aspects and carrying out the impact assessment in euroFOT. The goal of the document is to describe the methodology to such extent that it can be implemented by the VMCs without them running into fundamental (i.e. non-technical, non-practical) problems. Key questions in describing the methodology are:

- What data are needed for carrying out the assessment?
- What steps need to be taken in the assessment, or: how to calculate the impacts?
- What are the outputs the assessment needs to deliver?

Simply said, what is the input, what is the output, and how to go from input to output? This document provides the VMCs with a step by step plan to perform the hypothesis testing, answer the research questions and to provide the required input for the socio-economic impact assessment.

The methodology is split into four areas:

- User related aspects, containing:
  - Impact on driver behaviour;
  - Impact on driver workload;
  - Driver acceptance (defined as usability, usefulness, and social acceptability);
  - Trust; and
  - Function usage.

- Safety impacts, containing (for relevant crash types):
  - Changes in the number of slight injuries;
  - Changes in the number of severe injuries; and
  - Changes in the number of fatalities.

- Traffic efficiency impacts, containing:
  - Changes in kilometres driven;
  - Travel time changes;
  - Changes in the amount of accident related congestion; and
  - Homogenisation / reduction of congestion effects.

- Environmental impacts, containing:
  - Changes in fuel consumption; and
  - Changes in CO$_2$ emissions.

Some of the parameters listed above are measured directly in the FOT, others are derived. An overview of this is given in Table 2 in section 2.3.

1.2 Scope and work process

During the FOT both subjective (questionnaires and driver interviews) and objective data (CAN and video data) are gathered. Both sources of data are used for the assessment of user related aspects and the impact assessment. The assessment of user related aspects and traffic impacts is part of the data analysis, as well as the calculation of performance indicators. The performance indicators are input for the impact assessments and calculated...
at the VMCs. The methodologies for calculating the performance indicators are described by each VMC in their data analysis plan, for example [25].

Figure 1 presents the main steps of the data analysis; the highlighted steps form the impact assessment, for which the methodology is described in this document. In each VMC objective data are collected from the FOT vehicles and subjective data are collected from questionnaires and interviews. All data are checked with regard to data quality. After data processing (enrichment of data with additional attributes from a digital map, recognition of events and situational variables relevant), the relevant performance indicators (PI) are calculated for each VMC separately. The data are then stored in a database, again for each VMC separately. After each step the data quality is checked.

Using the calculated PIs, the hypotheses are tested by the VMCs by making use of parameters that are measured or have to be derived. The VMC specific hypotheses (formulated by the OEMs of a specific VMC) are tested only at the VMC, without result integration. The common hypotheses are assessed in all VMCs, provided that the function is tested for the VMC, i.e. for each VMC where ACC is tested the common hypotheses of ACC will be analysed. Before testing the common hypotheses, the results will be integrated, in order to have a common approach for the common hypotheses testing.

Based on the results of the hypotheses testing, performance indicators and situational variables, the global assessment (on traffic efficiency, safety and environment) is conducted by the VMCs. The assessment of user related aspects specifically makes use of the subjective data.

The methodologies for carrying out the assessments can be found in this document. The performance indicators are considered as a given (i.e. the data are analysed according to Figure 1 and the data analysis plan). In the methodologies it is described when and how hypotheses are tested, research questions are answered and results are integrated. For activities within the scope of this document the quality assessment is described. Quality of the data is not assessed; that is done in an earlier stage.
1.3 Relations with other work packages and deliverables

Interactions with other SPs and WPs of the project are essential for the work carried out in WP6300 and WP6400. The requirements for the assessments had to be considered by the other SPs from the beginning of the project. In this section the most important connections and interactions are described, with work packages and deliverables.

- The output of the work carried out in WP6300 and WP6400 (the methodologies for which are described in this document) is used as input for WP6500 (Socio-economic Cost-Benefit Analysis). WP6500 results in Deliverable 6.7 (Overall Cost-Benefit Study);

- In this document assessment methodologies are described. The results of carrying out the assessments are described in four separate documents: Deliverable 6.3 (Final results: User acceptance and user-related aspects), Deliverable 6.4 (Final results: Impacts on traffic safety), Deliverable 6.5 (Final results: Impacts on traffic efficiency) and Deliverable 6.6 (Final results: Impacts on environment). All assessment results are available in an overall document: Deliverable 6.1 (Final evaluation results);

- SP2 (In-Vehicle Systems for Driving Support) has provided the requirements and specifications of the selected functions in Deliverable 2.1 (Specifications and Requirements for Testing In-vehicle Systems for Driving Support);

- SP3 (Data Management) provides the data specification, data structure and format (database), data storage, and analysis tools. The requirements of SP6 with regard to data to be measured are considered in SP3;
- SP4 (Methodology and Experimental Procedures) has defined the evaluation criteria (experimental procedures) and performance indicators. SP4 and SP6 have very strong relations. Relevant documents are Deliverable 4.1 (Report on specification of performance indicators) and Deliverable 4.2 (Report on specification of experimental procedures); and

- SP5 (Vehicle and Test Management Centre) collects the data from the FOTs that is used for the assessments. This SP also takes care of quality management. A document that is important for SP6 is Deliverable 5.3 (Final delivery of data and answers to questionnaires).

1.4 Outline deliverable and reading instructions

The outline of this deliverable is as follows. Chapter 2 contains the general set-up of the methodology and the aspects common for all impact areas. Chapters 3, 4, 5 and 6 go into detail on the methodology for assessing the user related aspects, safety, traffic efficiency and environmental impacts respectively. In Chapter 7 the steps to be taken after the impact assessment are briefly described: scaling up and cost benefit analysis. To conclude, Chapter 8 includes some discussion items, such as challenges and possible solutions. Finally, references and annexes are given.

This document contains information on various levels. For readers who are interested in the evaluation methodology but do not have to carry out work with regard to evaluation, chapters 1, 2 and 8 are relevant. The people working on the assessment need to read the chapter corresponding with their area of assessment (chapter 3 for user related aspects, 4 for safety, 5 for traffic efficiency or 6 for environmental impacts) thoroughly, as well as the more general chapters 1, 2 and 8. People working on scaling up and/or the cost-benefit analysis need to read chapter 7.
2  FOT analysis methods: general set-up

In this chapter the general set-up of the methodology is described. All aspects that are common for all impacts areas (user, safety, traffic efficiency, and environment) are included. The chapter starts with a brief overview of FESTA, a methodology for carrying out FOTs that is used for developing the euroFOT assessment methodology. After this first section different aspects of the methodology are highlighted, that are applicable to all impact areas.

2.1  FESTA

FESTA is a European project that has provided support for FOTs by creating a handbook of good practice for a common FOT methodology [1]. In this section FESTA is briefly explained, and the aspects relevant for this deliverable are described more elaborately.

The FESTA handbook provides guidelines for the conduction of FOTs. It guides the reader through the whole process of planning, preparing, executing, analysing and reporting an FOT, and it gives information about aspects that are especially relevant for a study of this magnitude, such as administrative, logistic, legal and ethical issues. Another goal of the handbook is to pave the road for standardisation of some aspects of FOTs. This is very helpful for cross-FOT comparisons. FESTA is viewed as a common methodology for European FOTs.

The primary focus of the FESTA Handbook is on the evaluation of Advanced Driver Assistance Systems (ADAS) and In-Vehicle Information Systems (IVIS)—both in the form of autonomous systems and of cooperative systems. The Handbook is therefore designed specifically to guide the evaluation of such systems.

The different components of the Handbook are ‘summarized’ in the so-called ‘FESTA-V’ or ‘FOT Chain’. In this FESTA-V the steps that need to be carried out during a FOT are presented. In Figure 2 the FESTA-V is given.

The idea of the FESTA-V is that the steps / components have to be carried out in order of the arrows, with some overlap and iterations. The first and last steps (the ‘upper’ steps) deal with the more general aspects of a FOT and with aggregation of the results. The further down the FESTA-V the steps are located, the more they focus on aspects with a high level of detail, like how to store data in a database.
The steps that this deliverable is about are the pink boxes: research question and hypotheses analysis and system and function analysis. These two steps are explained below, together with the steps directly before and after (input and output for the assessment work).

- In Data Analysis performance indicators are calculated in order to be ready for the next steps (the assessment steps), taking into account situational variables (see section 2.2 later in this chapter);

- In Research Questions and Hypotheses Analysis the hypotheses are tested (for example: FCW increases the average speed → yes/no) and with these tested hypotheses research questions can be answered. For example, if the hypotheses ‘with FCW CO₂ emissions increase’, ‘with FCW less fuel is used’, and more hypotheses related to environment are tested, the research question ‘what is the impact of FCW on the environment?’ can be answered. Systematically, all research questions can be answered in this way; these impacts will be quantified, so they can be used in the socio economic cost benefits analysis.

- In System and Function Analysis the results of the FOT are generalized to a more global level in terms of traffic flow, traffic safety and environmental effects, so the system or function can be analysed on a more general level. A problem with generalizing results from a FOT is to know how close the participants represent the target population. It is often necessary to control for usage, market penetration and compliance (the function might be switched off by the driver) and reliability of the function;

- At the end of a FOT the Socio-Economic Impact Assessment is carried out. A consistent methodology for this maximises the comparability of the results across regions, ICT systems and FOTs. Components of the socio-economic impact assessment (not necessarily all components have to be carried out) are analysis of...
the safety benefits, efficiency benefits, environmental benefits and functions costs, cost benefit analysis, stakeholder analysis and a financial analysis.

As stated earlier, this deliverable is about Research Questions and Hypothesis Analysis and System and Function Analysis. Assumption is that data analysis is already carried out and performance indicators and situational variables are ‘ready’ for assessment. The System and Function Analysis needs to be performed in such a way that it results in the required input for in the socio-economic impact assessment.

In this document FESTA is used as a guideline for the methodologies that are developed. FESTA does not elaborate enough on all aspects of the methodology that are needed for euroFOT. Especially the System and Function Analysis part is described very briefly in the FESTA handbook. Where necessary, additions and small changes to FESTA are made.

2.2 Breakdown of research questions

Based on research questions, derived in SP2, hypotheses for each aspect of the analysis (e.g. safety, traffic efficiency, driver-related aspects etc.) were developed in SP2 and revised and prioritised in SP6. See annex 2 for the updated list of hypotheses. The hypotheses were used as a basis for identifying the required performance indicators and the corresponding signals to be collected by the data acquisition systems installed in the vehicles. For example, to test the hypothesis “ACC decreases the number of incidents”, the performance indicator “number of incidents” is needed. Depending of the definition of the incident, the signals to identify incidents have to be defined (e.g. vehicle speed, distance to forward vehicle, deceleration etc.). This process is depicted in Figure 3. In practice, the process has been more iterative than the picture suggests.

![Diagram of research questions, hypotheses, performance indicators, and signals](image)

Figure 3: Definition of hypotheses and required signals to be collected from the vehicles

Relevant events and situational variables have also to be taken into account when defining and testing the hypotheses.

Following on from this process, the following steps have been conducted at each VMC:
1. Identify needed data sources to provide needed information (e.g. vehicle data, environment data etc.)
2. Check availability of needed sensors to be integrated into the vehicles (e.g. radar sensors for additional information on other road users, video data for information on driver activities, eye tracking systems to detect eye movement of driver etc.)
3. Check availability of needed signals by means of the available sensors

Based on this information, the hypotheses defined in SP2 were reviewed with respect to feasibility, i.e. to check whether all needed signals are collected and available.

Within this feasibility check phase several steps have to be performed, in order to finalise the hypothesis list. First, as noted, the availability of the needed signals was checked at each VMC. If a hypothesis cannot be tested because the required information is not available, available alternative signals have to be sought (e.g., in the case that information on weather is not directly available because no rain sensor is available, information on the wiper signal and temperature signal might be used to derive data on weather conditions).

If this approach is not feasible, the corresponding hypotheses have to be partially reformulated, in order to find an alternative performance indicator for hypothesis testing. In some cases hypotheses may have to be removed at some VMCs because the required information cannot be collected by means of the available sensors. For example, the hypothesis “Using ACC the focus on primary task will decrease over time” can be tested by means of the performance indicators percentage of road centre (eye glance), glance frequency, and glance duration. These performance indicators can only be provided by means of video data or eye tracking data. But video data and eye tracking data are not available at all VMCs. At these VMCs the hypotheses cannot be tested. Table 1 presents the available data at the VMCs. At all VMCs subjective data are collected through questionnaires. In the Italian VMC, no objective data are collected.

Table 1: Collected data within the euroFOT project

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<th>Manufacturer</th>
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<td>Daimler</td>
<td>Passenger cars</td>
<td>-</td>
<td>-</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>BMW</td>
<td>Passenger cars</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>Italian VMC</td>
<td>FIAT</td>
<td>Passenger cars</td>
<td>533</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Swedish VMC</td>
<td>Volvo Cars</td>
<td>Passenger cars</td>
<td>-</td>
<td>-</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>Volvo Trucks</td>
<td>Trucks</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>70</td>
<td>10</td>
</tr>
</tbody>
</table>

2.3 Required data

Different types of data are required for the assessments. For the assessment of user acceptance and other user related aspects, both subjective and objective data are required. For the other assessments the majority of data that are needed are objective data. Sometimes subjective data are used additionally. Testing hypotheses and answering research questions is based on performance indicators, situational variables and events. The performance indicators that are needed vary per type of assessment. Therefore, these indicators are listed per chapter in this document, for the four assessments. The situational variables that are used are in principal the same for every assessment. However, it can occur that some situational variables are not relevant for a certain type of assessment. Events are mainly used in the safety impact assessment.

Situational variables are variables that describe the circumstances at a certain moment. These circumstances need to be measured in the FOTs. The first reason is to be sure that
the effects we see are due to the function and not due to differences in circumstances. The second reason is that in scaling up possible differences in circumstances between the FOT and the EU need to be taken into account. Therefore besides the performance indicators the following needs to be measured:

- Road classification
  - Type
    - Motorway
    - Rural
    - Urban
  - Speed limit: speed limit which is currently given (only for Speed Limiter / Cruise Control)
  - Number of lanes
  - Road curvature (only for Curve Speed Warning)
    - Strong curve (curve radius < 500 m)
    - Curve (curve radius > 500 and < 2000 m)
    - Not a curve (curve radius > 2000 m)
- Weather (measured: rain and temperature)
  - Good (dry and temperature above 3 °C)
  - Bad (rain or temperature below 3 °C)
- Lighting (some vehicles have sensors, for others a classification is made based on time)
  - Daylight
  - Twilight
  - Night
- Link / intersection
  - Intersection
  - No intersection
- Congestion / free flow (only for motorways)
  - Free flow
  - High density
- For trucks: mass, or empty/loaded
  - Empty
  - Loaded

The specification of the situational variables is harmonised for all VMCs. Some vehicles have different sensors than others, which requires a different specification, e.g. when lighting sensors are not available, the time of the day will be used to determine the lighting condition. The specification of the situational variables can be found in Annex 3.

Moreover, all performance indicators need to be separated according to the activation status and settings of the ITS. These exact statuses depend on the function, but can for example be:

- On
- Active
- Event (warning)
- Off
- Passive
- Function error

Especially in the safety impact assessment events are used. An event is something that happens in a specific period of time which is individuated combining (pre-processed) measures according to predefined rules. One or several preconditions must be fulfilled for one or several direct or derived measures. Events are yes/no occurrences; they are either valid at a certain point in time or not. Events can consist of sub-events, e.g. event car
following includes also sub-event close car following etc. These sub-events provide a further classification of an event.

A number of events have been defined in the FESTA project and in SP4. There is not one harmonised list or events that all VMCs measure. Also, the thresholds or parameters that are used can differ for the different VMCs. The following events are measured by at least one VMC:

- ABS intervention / activation
- Approach to intersection
- Car following
- Congestion
- Crash
- Critical distance
- Cut in
- Driver reaction to functional warning
- Driving in forbidden area
- Driving very slowly
- ESP intervention / activation
- Fast lane usage
- Hard acceleration
- Hard braking
- High acceleration
- High a_y (lateral acceleration)
- High yaw rate
- Incident
- Intersection
- Journey
- Lane change
- Lane departure (lane exceedance)
- Near crash
- Override ACC
- Overtaking manoeuvre
- Reverse
- Road departure
- Secondary task
- Severe steering wheel acceleration
- Sharp braking
- Speeding
- System warning
- Turn around
- Turn indicator
- Turning manoeuvre

In chapter 4 more can be read on the use of events in the impact analysis. The specifications of the events can be found in the Data Analysis Plans from the VMCs.

**Parameters for four impact areas**

As stated in section 1.1, the methodology is split into four impact areas. Each area has its own parameters. Some of these parameters are measured in the FOT, others are derived, and others are both measured and derived. In Table 2 an overview is given.
2.4 Types of effects and approaches to calculate effects

The effects of ITS can be classified in different ways. In euroFOT direct effects and indirect effects are distinguished; see Table 3 for an overview of the effects. This classification of types of effects is in line with the eIMPACT project (see for example [22]) and the way the efficiency benefits are classified in FESTA ([1], page 110). This classification does not follow the definition of direct and indirect effects in the description of the nine safety mechanisms as used in eIMPACT and FESTA, which is on a more detailed level.

Table 3: Overview of type of effects per impact area

<table>
<thead>
<tr>
<th>Impact area</th>
<th>Direct effects</th>
<th>Indirect effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>User related</td>
<td>Changes in driver behaviour, workload, acceptance, trust, usage</td>
<td></td>
</tr>
<tr>
<td>aspects</td>
<td>Safety aspects</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Change in number of injuries and fatalities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Efficiency aspects</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Change in kilometres driven, travel times</td>
<td>Change in accident related congestion</td>
</tr>
<tr>
<td></td>
<td>Environmental aspects</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Change in fuel consumption, CO₂ emissions caused directly by change in tactical driver behaviour (speed, acceleration)</td>
<td>Change in fuel consumption, CO₂ emissions caused by change in kilometres driven</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Change in fuel consumption, CO₂ emissions caused by a change in accident related congestion¹</td>
</tr>
</tbody>
</table>

¹ Based on input from the traffic efficiency impact assessment
Direct effects are caused directly by the function, for example a decrease in travel time caused by an increase of average speed, or a decrease in number of fatalities caused by a decrease of number of forward collisions. Indirect effects are ‘side effects’ caused by a direct effect of the function: for example a decrease in amount of congestion caused by a decrease in number of accidents.

For safety, efficiency and environment, this document describes how to go from calculated performance indicators to quantified impacts that can be used in the cost-benefit analysis. This includes translating small scale results to the EU level and considering different scenarios (varying for example penetration rates and traffic demand). The FOTs are carried out in a number of regions in Europe, and the effects found need to be scaled up from the equipped fleets and trips made in the FOT to the EU level. It needs to be taken into account that the effects found in the regions and conditions in which the FOT vehicles drove might be smaller or larger elsewhere, depending on the situations encountered by drivers across Europe. Many situational variables vary considerable across Europe, for instance motorway usage, prevalence of adverse weather, etc. Another thing to consider is that the fleet of FOT vehicles constitutes only a very minor part of the vehicle fleet on the road. For some functions, the effects may not be proportional to the penetration rate – for example when the equipped vehicles influence the driving behaviour of other vehicles.

As a consequence of the two issues mentioned above, it is proposed to use the following two approaches to obtain the desired results on efficiency and environment (for safety the situation is a bit different, this is explained in the safety methodology chapter): a linear approach and a modelling approach. The linear approach uses FOT data directly and effects are scaled up to EU level via situational variables. The modelling approach uses FOT data as input for traffic simulations or environmental models. With a traffic simulator the interaction between equipped and non-equipped vehicles can be modelled as well as higher penetration rates. The linear approach can in principle be applied to all functions. However it will possibly not bring the correct results since interaction effects and other nonlinear effects are not taken into account. When interaction effects are expected, traffic simulations will be carried out to capture these effects. Whether for a function it is necessary to use tools such as micro-simulation depends on two things:

- Do equipped vehicles influence other road users (equipped as well as unequipped)? For instance, a speed limiter that influences the speed of vehicles following an equipped vehicle.
- Can the function be modelled in micro-simulation models currently available and suitable for network analyses? If not, there is no use choosing the modelling approach.

2.5 Harmonisation of procedures and integration of results

In euroFOT, the eight different functions are being tested on five test sites. It is therefore quite possible that results differ between test sites due to factors outside the experimental protocol, such as geographical differences between test sites and countries as well as cultural differences, differences in size of the FOT (number of cars), accuracy of the data, climate and weather differences, legal differences (traffic laws and rules), etc.

To explain differences in results mainly due to such outside factors, WP6300 and WP6400 have given considerable thought on how to limit the variation in results between sites due to factors that are within experimental control. This work has mainly considered four areas.

The first area concerns harmonisation of procedures for hypothesis selection and testing. This involves making sure that sites testing the same functions query their databases in a similar way, ask for the same type of performance indicators and analyse the outcome with similar statistical tools. While relatively straightforward, this type of harmonisation
nonetheless amounts to quite a large body of work, given the size of the data and hypothesis sets.

The second area concerns integration of empirical results within each test site, i.e. what happens when two or more performance indicators show different effect sizes, or contradictory effects. A suggested way forward in this area is presented in subsection 4.7.2, in relation to the description of testing of objective data for safety impact analysis.

The third harmonisation area concerns the integration of empirical results between test sites. The main approach suggested here is to combine the assessments over the test sites by making (per performance indicator or hypothesis) a weighted average of the results. This weighting procedure would in its simplest form be based on the number of kilometres driven per test site, possibly divided over various situational variables such as road type and posted speed limit. For example, if on one test site 100 000 kilometres are driven with function X and the average speed decreases by 4%, and on another test site 500 000 kilometres are driven with function X and the average speed decreases by 1%, the weighted result is that the average speed increases by 1.5%. More sophisticated weighting procedures are also under consideration, such as applying weights which are proportional to the statistical “strength” of the results obtained. However, a final decision on how to proceed has to wait until the results start to come in and their properties can be understood and analysed further.

Should results diverge to a relatively large extent, it is proposed that besides giving one result (which is needed for the cost-benefit analysis) results will be shown for each test site separately, or that a range (from lowest to highest) is given instead of a single number. The same holds for results when split across situational variables: if there are large or unexpected differences in results for these variables (for example different types of weather or road types), it is an option to show the results split for certain situational variables. The reason for this is that in as much as the harmonisation of the testing procedures described above is successful, a remaining result difference might well reflect real differences between test sites which lie outside the experimental protocol, and which therefore would be interesting to report for further investigation in future projects.

The fourth harmonisation area concerns bundled functions. The vehicles in euroFOT are production vehicles rather than experimental vehicles. For reasons explained in the next section these vehicles are therefore equipped with function bundles rather than stand alone functions. Based on this, a conceptual way of disentangling which function has which effect when such bundles functions are deployed in the treatment phase, and also to what extent inter-function influences is a worry, had to be developed. This development work is further described in section 2.6.

2.6 Disentangling the effects of bundled functions

The hypotheses to be tested during ADAS evaluation are usually formulated based on the assumption that it is possible to determine, in isolation, the impact on driver behaviour, safety, efficiency and environment. However, the vehicles used in euroFOT are modern production vehicles. For such vehicles it is the norm rather than exception to have multiple ADAS. This is true also for the euroFOT vehicles; i.e. most contain multiple ADAS. The following function bundles are being tested in euroFOT:

- FCW + ACC (German1 – Ford)
- FCW + ACC + LDW (Sweden – Volvo)
- FCW + ACC + LDW + IW + BLIS (Sweden – VCC)
- ACC + LDW (German1 – MAN, VW)
- SL + CC (French)
The functions FEA, CSW and SafeHMI are not bundled (only one function per vehicle), so for these functions disentangling the effects is not an issue. ACC and LDW are also tested in isolation, besides being in function bundles.

The issue of how to disentangle the effects of bundled functions evaluated in FOTs – either through experimental design or via the use of data analysis techniques – is one that has not been discussed before in the literature. The basic question is: “Can we legitimately test hypothesis X for function Y, given that the impact of this function on behaviour may be influenced by other co-existing function(s)?” This important issue was considered by a “System De-Bundling Task Force” convened within WP6300, and a paper was written that discusses the issue in detail [28]. This section essentially contains a summary of the findings and conclusions for euroFOT drawn in this paper.

Different debundling approaches are possible, the choice depends on the (goals of the) FOT in question. For euroFOT, one of the main goals is to make an impact assessment for EU27. This implies making a projection on the extent to which the functions have effect on safety, efficiency and emissions on the European-wide level if the evaluated ADAS were to be widely deployed in Europe. For this assessment to be realistic, one has to take into account the forms under which the ADAS in question might be deployed. This brings back the initial remark made, i.e. that vehicle manufacturers usually sell function bundles based on particular sensor capacities rather than stand-alone functions.

The task force recommended partitioning the problem into two separate challenges; the impact challenge and the interaction challenge. The impact challenge refers to the risk that, with bundled functions, it might not be possible to tell two functions apart in terms of which impact they have. The interaction challenge refers to a different type of worry, which is that the impact of one function might be enhanced or negated when another function is also present in the vehicle. Below, strategies for dealing with these two challenges are presented and conclusions for euroFOT are given.

**The impact challenge: how to disentangle function impacts**

In any approach which looks at function effects on an individual level, there is the risk of inflating the impact assessment by double counting. Thus, while in a sense obvious, it is worth stating clearly that when two or more different functions are designed to target the same impact, their combined effect can only realise that impact once. This impact challenge is most relevant to the safety effect. E.g. the combined impact of a bundle cannot exceed a 100% crash reduction for a specific crash type. For impact assessment, the individual functions therefore cannot be the primary unit of analysis. Instead, a bundle addressing a certain crash type becomes the primary unit of analysis.

However, even if the crash type rather than the function is the primary unit of analysis, this does not solve the issue of how to identify the relative contribution of each function. To do this, again for the example of safety effects, two more things are needed. The first is an accident model that allows separation of crash contributing factors into a sequence of some sort, and the second is detailed knowledge of what those factors are, i.e. knowledge of the underlying causation mechanisms for the targeted crash type. If these two things exist, it is possible to analytically-empirically tell the relative impact of two or more functions addressing the same crash type apart, by first analysing each function in terms of which contributing factors it is targeting, and then positioning it relative to other function(s) based on where in the contributing factor sequence the targeted factor(s) occur.

Defining an accident model is relatively easy. The literature is abundant with models that describe accidents as the results of one or more sequential chains of contributing factors combining in space and/or time. One example of such a model that has been used in in-depth crash causation investigation projects is the Driving Reliability and Error Analysis Method (DREAM; [29]), but many more exist (for a review of the implications of selecting different accident models, see [30]).
Detailed knowledge on underlying causation mechanisms is less easy to come by. Research on accident causation with a sufficient level of empirical detail for ADAS development and evaluation is still in its initial phases. However, some good examples of progress are being made, for example the 100 Car Naturalistic Driving study. Real world situations which both FCW and ACC can be viewed as addressing are situations where emergency braking is required to avoid colliding with a lead vehicle. In the 100 Car study it was found that these situations occur very unexpectedly from the driver’s point of view [13].

Given that this mechanism description is accurate, it becomes possible to reason about the relative impacts of FCW and ACC following the principles above. For example, one could assume that ACC primarily influences distance keeping to lead vehicles, while FCW mainly helps the driver respond faster once something unexpected actually occurs. ACC can thus be positioned before FCW in the sequence of events, i.e. it principally acts as a barrier that prevents drivers from exposure to unexpected events. FCW on the other hand only triggers inside those events. If ACC if a successful barrier, one would then expect a reduction in the frequency of unexpected lead vehicle braking events when ACC is in use, while FCW if successful would lead to faster driver response times for the unexpected events that do occur. Both these effects can be investigated empirically, and the relative efficiency of each function in addressing its part of the overall crash causation mechanism can thus be discussed.

A similar but more complex example of the same type is provided in Table 4. Here, the potential benefit of fitting a single vehicle with four different ADAS which all address crashes related to inadvertent lane departures is estimated. The example starts from a hypothetical crash population of 100 000 crashes. It positions each function in relation to the sequence of typical contributing factors that precede and surround an inadvertent lane departure-related crash, and assesses the impact each function can be expected to have on that particular contributing factor. In the example, the first function mitigates 15 000 crashes. Then the effectiveness of the second function is applied to the 85 000 remaining crashes, etc.

Table 4: Hypothetical example of sequential, scenario based, safety impact analysis for a hypothetical crash population of 100 000 lane departure crashes

<table>
<thead>
<tr>
<th>Crash Avoidance Potential</th>
<th>Pre-driving phase</th>
<th>Normal driving phase</th>
<th>Conflict phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contributing factors</td>
<td>Driving while under influence</td>
<td>Fatigue &amp; low vigilance</td>
<td>Inside or outside vehicle distraction</td>
</tr>
<tr>
<td>ADAS addressing the factor(s)</td>
<td>Alcolock</td>
<td>Impairment Warning Lane Keeping Aid</td>
<td>Lane Departure Warning</td>
</tr>
<tr>
<td>Factor prevalence (how often is the factor involved)</td>
<td>50% of crashes</td>
<td>50% of crashes</td>
<td>75% of crashes</td>
</tr>
<tr>
<td>Function efficiency (percentage of drivers helped)</td>
<td>30%</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>Crashes mitigated</td>
<td>15000</td>
<td>12750</td>
<td>16256</td>
</tr>
<tr>
<td>Crashes left to address</td>
<td>85000</td>
<td>72250</td>
<td>55994</td>
</tr>
</tbody>
</table>

For traffic efficiency and environmental effects the longitudinal acceleration is used. This longitudinal acceleration is affected mainly by continuously active functions such as ACC and SL/CC. The impact of a FCW system on efficiency and emissions is minimal since the
warnings are issued only occasionally. The longitudinal acceleration could also be slightly influenced by lateral functions, however it will not be possible to separate this effect.

**The interaction challenge: how to understand interaction effects**

The second challenge to address when evaluating bundled functions is potential function interactions. In other words, there is a possibility that the effect of one function is influenced by the presence of another. If this happens, a particular function’s impact in the bundled condition might be different in the bundled compared to the standalone deployment condition, in which case it becomes difficult to say what the “true” impact of the function is.

Unfortunately, the mechanisms through which these interactions may come about are even less well established than the crash causation mechanisms sought above. The main effort in addressing this issue therefore lies in identifying one or two relevant interactions that are meaningful to test for within the project, based on the very long list of possible interactions creative researchers of various affiliations have made. Here, the task force essentially arrived at one interaction that seemed worthwhile and empirically possible to investigate, centred on changes in lateral control as a function of ACC usage.

The hypothesised mechanism is that driving with ACC might take a certain workload away from the driver in terms of what is required to maintain longitudinal control, and thus free up attention that can be devoted to other things. If this happens, the driver might devote some of that attention to improve lane keeping, in which case the variation in lane positioning and the number of lane exceedances might be reduced. On the other hand, if the driver devotes that attention to non-driving activities, one could expect a reduction in lateral control, and thus an increased risk of receiving a lateral warning.

While many more interactions could be hypothesized and tested for, it was not seen as feasible to pursue this topic much further given the time and resources available in the project.
Conclusions for euroFOT

In terms of disentangling safety, traffic efficiency and environmental impacts in euroFOT, one finding of the task force is that in the deployed bundles, the issue of two functions addressing exactly the same contributing factor does not seem to arise. This most likely reflects common engineering sense in the ADAS development process, i.e. a desire not to waste resources on trying to solve the same problem twice. Instead, the functions in euroFOT can be bundled based on the crash type they intend to address, and in relation to that crash type can be arranged in the same type of sequential order as in the above examples.

To illustrate this point, in the most complex bundle above which is the Swedish FCW+ACC+LDW+BLIS+IW bundle, one can say that ACC and FCW influence the same crash type (rear end crashes) and should thus be considered bundled in terms of the safety impact analysis. However, the two address different parts of the crash causation mechanism, and can therefore be analysed in empirical separation given sufficient amounts of relevant data.

IW and LDW target the same crash type (run-off-road crashes) and should thus be considered bundled in terms of the safety impact analysis. However, the two aim for different contributing factors, and can thus be analysed in empirical separation given sufficient amounts of relevant data.

BLIS can be viewed as conceptually debundled from the other functions. BLIS is primarily intended for crashes related to intentional lane changes. While this on some kinematic level might overlap with situations where LDW would activate, the underlying crash causation mechanisms are different. While BLIS addresses under informed but intentional lane changes in a multiple lane, dense traffic environment, LDW addresses inadvertent lane departures typically in free flow, low workload driving conditions.

In terms of interaction effects between functions in this bundle, the hypothesis that the task force decided to pursue was that driving with ACC might take a certain workload away from the driver in terms of longitudinal control, and thus free up driver attention that can be devoted to other things. If that attention goes to improve lane keeping, the variation in lane positioning and the number of lane exceedances (and thus the associated frequency of IW and LDW) might be reduced. If it goes to non-driving activities, lateral control might instead be reduced, (thus an increased risk of receiving an IW or LDW). In the EMPHASIS project [53] it was shown that the latter is the case: ACC leads to reduced lateral control.

As this type of reasoning will be applied to all bundled functions in euroFOT, it follows that for some of the hypotheses in Annex 2A, the unit of analysis will not be a single function, but rather a combination of two or more functions. For FCW it is for example not possible to test the behavioural impact in isolation, because it is bundled with other functions in three different function configurations. Where it is decided that the effect of a function cannot be disentangled from the effect of another function, this will be highlighted in the final report, along with the implications of this for the interpretation of the data deriving from the hypothesis testing process.

For the socio-economic cost benefit analysis this means that quantified safety, efficiency and environmental effects will be provided for the bundles ACC + FCW, IW + LDW, SL/CC, and the single functions BLIS, FEA, CSW and SafeHMI.
3 User-related aspects

3.1 Introduction

In chapters 1 and 2 of this document the introduction to the assessments and the general set-up of the assessment methodology are described. In this chapter the methodology for assessing the user related aspects is described in detail. It is necessary to evaluate the impact of the ADAS on driver behaviour and to evaluate how acceptable they are to drivers. These evaluation activities are being undertaken in WP6300 (User Acceptance and User-Related Aspects Evaluation) of the euroFOT project. These evaluations are being performed by the VMCs at each euroFOT test site, for the functions for which they are responsible.

The assessment of user related aspect is based largely on hypotheses testing. Therefore this chapter describes how hypotheses are tested. This includes also data processing and PI calculation. To be complete, these steps are described in this chapter although they are strictly not in the scope of the impact assessment.

This chapter describes hypotheses testing from a behavioural point of view, also taking into account safety. However, the methods described are more generally applicable and will also be useful for hypotheses on efficiency and environment.

Harmonized data analysis methodologies for the evaluation of the impact of the functions on driver behaviour and acceptance were developed by a Harmonisation Task Force created in WP6300. Here the harmonised methodologies for carrying out what will henceforth be referred to as the “behavioural impact assessment” in euroFOT are described. The goal of this chapter is to describe the methodologies to be employed to support this assessment.

This introductory section covers the following issues: the aims of the behavioural impact assessment (3.1.1), functions, required performance indicators, research questions, hypotheses and other data (3.1.2), a work process (3.1.3) and outline of the rest of this chapter (3.1.4).

3.1.1 Aims of the Behavioural Impact Assessment

As stated in the Description of Work for WP6300 of the euroFOT project, the aim of the behavioural impact assessment is to analyse, for each function tested:

- Its impact on driver behaviour;
- Its impact on driver workload;
- Driver acceptance of the function (defined as usability, usefulness, and social acceptability);
- Trust in the function;
- Function usage; and
- Exposure.

3.1.2 Functions, research questions, hypotheses and data needs

3.1.2.1 Functions to be assessed

Descriptions of the functions tested in euroFOT can be found in [20]. All functions will be evaluated on driver behaviour and acceptance. This will be done according to the information given in section 2.6 on debundling.
3.1.2.2 Research Questions and Hypotheses

Description of Work for WP6300

The Description of Work for WP6300 specifies that for each function the following aspects must be analysed:

- **Acceptance**
- **Trust**
- **Driver workload**
- **Usage of function**
- **Usability**
- **Usefulness**
- **Social acceptability**
- **User practices** (i.e. changes in the way the drivers use/interact with the function over time e.g. heuristics and rules how the driver commonly uses the function and if he remembers how to use it.)

Furthermore, the Description of Work for WP6300 specifies that the following research questions have to be answered for each function:

1. What features of the function, in terms of **usability** (e.g. accessibility, readability, controllability, compatibility while driving) influence acceptance?
2. What features of the function, in terms of **usefulness**, influence user acceptance?
3. Does acceptance change with experience?
4. Does trust in the function change with experience?
5. Do drivers find the function more usable with experience?
6. Does usage of the function change with experience?

In Annex 2A a list of hypotheses under consideration for testing in order to address these research questions can be found. This list contains the hypotheses for the behavioural impact assessment, and also hypotheses for the other impact areas. The hypotheses are grouped into the following generic categories:

- **Driver behaviour**
- **Acceptance**
- **Trust**
- **Usage**
- **Workload**
- **User practices**
- **Abuse/Misuse**
- **Safety**
- **Efficiency**
- **Environment**

Note that the hypotheses in Annex 2A show only a partial overlap with the list of hypotheses that can be found in deliverable 2.1 [49]. This is because in deliverable 2.1, a very large set of tentative hypothesis was identified, pointing to various interesting areas of potential investigation. Since then, the hypotheses have been iteratively refined and reduced in number over the course of the project to make the list suitable for data analysis. This refinement involved several processes: prioritising hypotheses, simplifying hypotheses,
reducing the ambiguity of hypotheses, reducing overlap between hypotheses, eliminating hypotheses that could not be tested for technical or other reasons, and considering whether the hypothesis in question relates to a single function or bundle of functions. Note also that the list in Annex 2A represents the current status of that iterative work, i.e. it is not conclusive. Further modifications may take place before the project finishes.

In the behavioural impact assessment some hypotheses which fall within the “safety” category are taken into account. This is because these hypotheses do not fall within any other WP in SP6, and several of these hypotheses could equally be regarded as falling under the category of driver behaviour.

Other Considerations

The misuse or abuse of a function may be considered an indirect measure of driver acceptance. Misuse is defined here as the intentional or unintentional use of a function in a manner that was not intended by the function designer e.g. setting top speed for a speed limiter while driving in a low gear. Abuse is defined here as use of the function in an illegal manner e.g. setting the cruise control to 5 km/h above the speed limit to avoid speeding fines knowing that police will tolerate slight violations. The WP6300 research team proposed that an additional hypothesis should be included in the hypothesis list to assess this aspect of driver acceptance (see Annex 2A, i.e., the “Plus Abuse/misuse” hypotheses).

3.1.2.3 Data Needs

The hypotheses to be tested will, as noted, rely both on subjective data and objective data. The subjective data are being collected via a harmonised, purpose-designed, questionnaire developed in WP4300, with input from WP6300. Some additional questions have been developed by some VMCs, to answer some of their own specific research questions. The Italian VMC only uses subjective data to test its hypotheses; the other VMCs rely on both objective and subjective data to test their hypotheses.

Some of the outputs of the behavioural impact assessment will be used in Work Packages 6400 and 6500 to support the assessment of safety impacts, traffic efficiency impacts and environmental impacts. These outputs are specified, for these assessments, in chapters 4, 5 and 6, respectively.

3.1.3 Work process

IFSTTAR, as leader of WP6300, coordinates the analysis effort. The VMCs will do the actual implementation and analysis: that is, testing of hypotheses using the methodology described in this chapter.

3.1.4 Outline

Section 3.2 of the chapter (Hypothesis Testing – Objective Data) provides an overview of the analysis methods to be used to test those hypotheses that rely on objective data. In Annex 2B of this report, worked examples are provided of the application of these methods for each of three generic types of hypotheses (relying on objective data) that characterise the list of hypothesis in Annex 2A.

Section 3.3 of this chapter (Hypothesis Testing – Subjective Data) provides an overview of the methodological approach to test those hypotheses that rely on subjective data. In Annex 2C of this report, worked examples are provided of the application of these methods for each of three generic types of hypotheses (relying on subjective data) that characterise the list of hypothesis list in Annex 2A.
In the appendices shortened descriptions of the functions can be found, and descriptions of the simulation tools of TNO and IKA.

3.2 Hypothesis Testing – Objective Data

This section describes the methodology to test the hypotheses in Annex 2A which rely on objective data.

3.2.1 Preparatory activities

The chosen approach to analyse the objective data within euroFOT is based on the FESTA methodology, see section 2.1. The data collected during the collection phase are stored in a database. In that database the collected measures as well as the additional information that have been determined during the processing phase are stored and can be used for performing the analysis. The additional information is generated by means of different processes. For instance, information on road type, speed limit and curvature are not available on the vehicle’s CAN bus. This information is determined by means of the collected GPS signal. Furthermore, relevant events (e.g. incidents, lane change manoeuvres etc.) as well as situational variables (e.g. weather condition, lighting condition, traffic density etc.) are collected by means of processes, which search the data with respect to defined patterns (e.g. exceedance of a certain deceleration value as a trigger for detection of incidents).

The approach for data processing varies between the VMCs – especially the processes for detection of relevant events and situational variables. These differences are mainly caused by the different data acquisition strategies. For instance, in the German1 VMC, a fully automated process for detection of events and situational variables (SV) has been implemented. The validation of the reliability of the event and SV detection have been conducted during the piloting phase, where vehicles have been equipped with video cameras, in order to collect video data. Based on these data the reliability of the algorithms for event detection has been gradually improved. In Figure 4, an example for steps performed to improve the detection reliability of the incident event is presented.

![Figure 4: Approach for improvement of detection reliability for the incident event at the German1 VMC](image-url)
In the other VMCs (e.g. the Swedish VMC) where video data are collected the validation of the detected events is performed within the data processing phase. The events detected by means of automated processes are validated manually with the collected video data in an iterative process where the thresholds and algorithms used in the automated process are subsequently refined. By this iterative refinement of triggers misses are checked for. After the validation phase, the detected events as well as situational variables are stored on the database and can be used for testing of the hypotheses.

In the following subsections, the key steps required for testing the behavioural hypotheses in Annex 2A (relying on objective data) are discussed and a practical example of how such a hypothesis can be tested is presented.

### 3.2.2 Generic Approach

To test hypotheses based on objective FOT data, a number of steps need to be carried out to prepare and sample the analysis data. In this subsection, these steps will be described briefly. Some of the steps have to do with data processing and PI calculation and are not a part of the impact assessment, but to be complete they are described here too. Afterwards, an exemplary walkthrough of one of the hypotheses will be given. The overview of the process is given in Figure 5.

![Figure 5: Process for hypothesis testing using objective data](image)

The hypotheses have a certain commonality in terms of data preparation and extraction. Four general ways of preparing the data for the analysis can be distinguished, depending on the focus of the analysis:

1. Comparing the average state of some variable like speed or headway in baseline (no function available) and treatment (function available)
2. Comparing how often a particular type of event or condition occurs in baseline and treatment (like the frequency of near crashes)
3. Studying if function usage changes over time, e.g. if the driver uses a function more often once it has become available
4. Studying whether function presence influences some other aspect of driver behaviour, such as the proportion of time spent doing secondary tasks

The example provided in subsection 3.2.3 elaborates on the first of these analysis types. For similar examples of the other types of analyses, see Annex 2B.

#### 3.2.2.1 Pre-processing

To get to the actual testing, the data need to be pre-processed first – that means, pre-processing all calculations which need to be carried out on the raw data level before one can
start selecting data for the hypothesis testing. This involves procedures for deriving measures, applying frequency filtering on signals, etc.

3.2.2.2 Comparison situations

The next step is to deal with the issue of defining which parts of the collected driving data should to be compared. Hypothesis testing principally involves some form of condition comparison. Therefore one must decide on the conditions which are to be compared. For example, should mean speed with and without ACC be compared only on highways or on all types of roads?

3.2.2.3 Controlled factors

After the conditions have been defined, one needs to define the controlled factors for which the dependent measures, or performance indicators (PIs), will be compared. For example, to analyse whether the average speed changes when LDW becomes available, one must decide which treatment data to include. Should everything in the treatment phase be considered (i.e., is it enough that the driver has the function in the vehicle) or should one look only at the portion of the data where LDW actually can be activated and used (i.e., speeds above 60 km/h); and, if so, should one be even more restrictive and only select data where the road markings are sufficiently visible for reliable lane tracking? Clearly, making this type of decision comes back to how one conceptualises the effects of LDW; that is, whether one sees them as very local in time and space or as more general in terms of overall behavioural adjustment.

One also needs to state whether data should be organized per-driver or per-vehicle (given that driver identification is reliably logged). If driver identification is available, it is probably better to organize data per-driver and not per-vehicle – a per-driver analysis of the results enables repeated measures analysis which is more likely to show statistical significance. Further, driver behaviour over time (for instance related to hypotheses such as “ACC usage increases over time”) can be assessed only if the data are organized on a per-driver basis.

3.2.2.4 Quality checking and filtering

Once these definitions are in place, one needs to check the data quality according to some criteria (are there a lot of missing data; can the data be trusted as is or does it need corrections; is there some biased form of data loss?) Before computing the performance indicator some filtering may also be needed, for example to eliminate high-frequency components from a signal.

3.2.2.5 Chunking

When definitions and quality measures have been addressed, and if the hypothesis to be tested is looking for some average difference, then it is time to chunk the data. Chunking means that the identified segments (i.e., those selected by applying control factors to the dataset) are divided into chunks of data of equal size. Chunking is applicable to all PIs which are based on time series data. Chunking has two important effects for the analysis. First, it guarantees that PIs are calculated on samples of equal size, which reduces variability. Second, it provides a simple way of keeping track of how much data per condition was included in the analysis.

For most of the hypotheses that require chunking, the optimal chunk size will be a trade off between discarding as little data as possible and still computing a reliable dependent measure. The reason for this is that every time a segment is divided into chunks some data is lost. Specifically, segments shorter than the desired chunk-length and ending parts of
segments shorter than the desired chunk-length are discarded. Thus, in general, smaller chunks result in less discarded data. However, choosing very short chunks to discard little data is not acceptable for some PIs, as those require a minimum number of samples to be reliably calculated; in such cases, this minimum number of samples sets a constraint on the minimum acceptable length of the chunk.

3.2.2.6 Performance Indicators – calculation and potentially merging

When the above has been completed, it is time to calculate the PIs, such as average speeds or event frequencies. Also, if the data were chunked, it is necessary to decide if and how it should be merged (so far there’s one data point per chunk). Merging can be simple, such as calculating the average, or it can be more complex. Specifically, for a performance indicator like MeanSpeed, merging can be just averaging. However, for something like Minimum Time Gap, averaging would result in considering data from only one chunk from each of the data sets. For this reason, merging depends on the different hypotheses and dependent measures, and more than one merging procedure can be specified, e.g. by averaging over different time windows.

3.2.2.7 Statistical analysis

The final step is statistical analysis of whether there is a significant difference between the comparison conditions. Depending on the setup of the procedure above, various statistical models may be validly applied (ANOVA, t-test, Mixed Generalised Linear Models, etc). The statistical analysis should also include comparing the data based on some set of variable factors, such as time of day, weather and road type to determine whether the dependent measure is influenced by these.

Using these steps, all user related hypotheses based on objective data can be tested (see annex 2A.

3.2.3 Example: Testing the hypothesis – “ACC Decreases Mean Speed”

Below, a specific example is given for testing the hypothesis “ACC decreases mean speed”.

3.2.3.1 Pre-processing

Since Vehicle_velocity also will be a controlled factor used to select the data it is important that spikes in speed do not result in the fragmenting of data. Therefore a filter with hysteresis should be applied on Vehicle_Velocity.

This filter is intended to distil 3 speed ranges (low: below 50 km/h; medium: between 50 and 70 km/h; and high: above 70 km/h). These speed ranges are selected to match the typical speed conditions under which rear end crashes occur. This means that the influence of ACC can be studied separately for these speed ranges in the safety benefit analysis. Therefore the filter needs to take into account the speed thresholds: 1) 50 km/h and 2) 70 km/h and acknowledge a change in speed range when speed is below/above one of these thresholds for at least 10s.

This filter is used to limit data fragmentation by neglecting changes in speed range when shorter than 10s. Note: this filter is used to make possible chunking of longer segments which makes it possible to use longer chunks. An example is given in Figure 6.
3.2.3.2 Comparison situations

Defining a baseline for ACC is one of the most difficult baseline definitions in all of euroFOT. The most relevant comparison is probably with how drivers select speed in relation to their use of regular Cruise Control (CC) in baseline. This results in a total of four comparison situations.

- **CC not in use**: experimental condition = baseline AND CC_state = off or standby
- **CC available and in use**: experimental condition = baseline AND CC_state = active
- **ACC not in use**: experimental condition = treatment AND ACC_State = off or standby
- **ACC available and in use**: experimental condition = treatment AND ACC_State = active

There is a baseline in each VMC. The details are given in euroFOT deliverable 4.2 [52].

3.2.3.3 Controlled factors

Data should be filtered based on when CC/ACC actually can be used. This means excluding data where driving speed is below 30 km/h. The reason for this filtering is that CC/ACC cannot be used at such low speeds (they are not available), and therefore cannot influence speed choice. This also means that very low speeds in congested traffic are not an issue, as the filter will take those away anyway.

Also, data should be sorted according to driver_id, driver experience and speed ranges according to the following:

**CC/ACC activation feasibility definition:**
- **Vehicle_velocity** > 30 km/h (i.e. lower speed limit for CC/ACC functionality)
- No congestion – in congested traffic speed is not self selected but determined by surrounding traffic (Traffic_Density = medium or low; if this measure is available)
- Not during overtaking manoeuvre
- CC/ACC is not overridden – i.e. if ((Acc_pedal_pos \approx 0) AND (ACC_State or CC_State \text{ active})) data should not be considered.

**Driver identity definition:** Ideally data should be organized on a driver basis using the DriverID so that a comparison situation can be used in the statistical analysis as a within-subjects factor with repeated measures.

**Driver experience definition:**
Drivers should be clustered according to 2 levels of experience:
- Low: \text{Driving}\_exp < 5 years
- High: \text{Driving}\_exp \geq 5 years

**Velocity range definition:**
Data should be organized based on 3 velocity ranges (after applying the hysteresis filter):
- Low: \text{Vehicle}\_velocity < 50 km/h
- Medium: \text{Vehicle}\_velocity > 50 km/h AND \text{Vehicle}\_velocity < 70 km/h
- High: \text{Vehicle}\_velocity > 70 km/h

3.2.3.4 Chunking the data and calculating and merging PIs

Data should be chunked. Optimal chunk size should be calculated according to the procedure below. Based on previous analysis, chunks may result in being 1- to 10- minutes long.

Chunk size is a determinant decision which may influence the results and the amount of data utilized for the analysis. The optimal chunk size (for this specific hypothesis) is a trade off in between too long: very reliable for PI but wasting data and too small: not reliable for PI calculation but able to utilize most of the data. Plotting distributions of chunk size (see Figure 7) may help the analyst to find the optimal compromise for chunk size.
By looking at Figure 7, the analyst can understand how much data are discarded as a function of the segment’s time-length. Specifically, it appears that choosing 25s-long chunks would result in using only 20% of the data.

If Figure 7 can help the analyst to decide what the maximum acceptable chunk size is, information about the PI and the dynamics captured by the PI can be used to set a minimum acceptable chunk-size. For example standard deviation of lane offset may be reliable only if calculated on chunks that are at least 10s long.

Mean Vehicle_velocity is not very sensitive and can be calculated over a very limited number of samples; therefore taking into consideration most of the data.

For each chunk the PI mean_velocity according to the definition in the PI matrix should be calculated. The mean of all mean velocity PI’s from each chunk should be saved in the final results structure.

3.2.3.5 Statistical analysis of main and variable factors

For this example, the appropriate statistical test would be an ANOVA repeated measures with (DriverID) and baseline/treatment as 2 main within-group factors and then speed ranges, driver experience and CC/ACC state (off vs. active) as between-group factors.

Based on the results from the statistical analysis, it may be good to compare that the following variables are equally distributed in the data sets especially where statistical
significance has been found. This means that, for each chunk, the following variable factors should be added up in the merging procedure.

- **Rush hour:**
  - Compare the amount of data at different times of the day from of UTC\_time in rush hours (07:00-09:00 or 16:00-18:00) during week days and non-rush hours (rest of time)

- **Road type:**
  - Compare the amount of time spent in rural versus motorways (RoadType)

- **Weather:**
  - Compare the distribution of Weather situational variables (rain, low temperature (below 3°C), darkness) from the weather-related measure

### 3.2.3.6 Used and discarded data

To understand which drivers contribute most to the result of the hypothesis testing, as well as the size of the data used in proportion to all collected data, missing, discarded and used data should be tracked as follows:

1. **MissingData** shall be calculated, in seconds for each variable factor and should be reported as cumulative for each driver.

2. **DiscardedTimeForChunking** shall be calculated, in seconds for each driver, as a cumulative of all data lost in chunking (either because it was left out or because the data sample was too short to account for one chunk).

3. **DiscardedDataForLowQuality** shall be calculated, in seconds for each driver, as a cumulative of all data of quality not good enough.

4. **OtherDiscardedTrips**: all trip\_IDs not possible to process because the driver was not recognizable should be saved here.

5. **UsedDataPerDriver** shall be calculated, in seconds for each driver, as a cumulative of all data used to calculate PIs.

6. **TotalUsedTime** shall be calculated as the sum of all UsedDataPerDriver from all drivers (it is a redundant measure that can be calculated in the end of the analysis)

### 3.3 Hypothesis Testing – Subjective Data

This section describes the methodology to be used to test the hypotheses in Annex 2A which rely on subjective data.

#### 3.3.1 Data needs

A purpose-designed questionnaire was developed in WP4400 of the euroFOT project, with specialist input from Work Packages 6300 and 6400. The steps involved in developing the questionnaire are described in Deliverable 4.2. The questionnaire contains all questions necessary to yield data that can be used to test those hypotheses in Annex 2A, and some additional hypotheses tested in WP6400, that cannot be tested using data derived from vehicle data acquisition functions. The hypotheses for the behavioural impact assessment that require for their testing data from the questionnaire are shown in the Table in Annex 2A. The table also contains the variable names for those items in the questionnaire required to test each hypothesis.
The questionnaire is divided into five parts (referred to as Screening and Times 1, 2, 3 and 4), each part of which is administered at different times during the FOT. The Screening, Time 1 and Time 2 questionnaires are administered during the baseline period, prior to function activation (Screening and T1 at the beginning of the baseline period, and T2 at the end of the baseline period). The Time 3 and 4 questionnaires are administered during the treatment period, after function activation (at the mid and end points of the treatment period, respectively). The data collected in the 5 parts of the questionnaire are described below.

Some of the data collected via the questionnaire, although not necessary to test specific hypotheses, have been included to enable the data analysis in SP6 to describe the subject sample and obtain the profile of the sample (e.g., personal details), explain findings that are not predicted by the hypotheses (e.g., Attitudes Towards Target Behaviours), to yield data to improve function design (i.e., System Design; System Use), and to understand purchasing intention as a result of function use (i.e., Affordability). Some data are collected at one or more points during the FOT to enable VMCs to enable data analysts to test hypotheses relating to changes in self-reported attitudes and behaviours over time (e.g., Mental Workload). The following data will be collected from the different parts of the questionnaire:

**Screening Questionnaire (before function use):**
- Driving experience and travel patterns
- Experience with technology
- Personal details (e.g., age, gender, etc.)

**Time 1 Questionnaire (before function use):**
- Travel patterns (in more detail)
- Accident record
- Attitudes towards target driving behaviours (e.g. tailgating, speeding)
- Personality scale (sensation seeking)

**Time 2 Questionnaire (before function use – end of baseline period):**
- Affordability (what drivers think they would be willing to pay to buy and maintain function)
- Mental workload scale (what drivers think workload will be; overall, and in 32 specific scenarios e.g. "on rural and familiar roads"; continuous scale from 0 –No effort to 112 –extreme effort)
- Function acceptability scale (measures 20 attributes of acceptance, each on 5-point scale e.g. useful XXXXX useless; etc.)

**Time 3 Questionnaire (administered midway through trial):**
- Function acceptability scale (repeat of T2)
- Mental workload scale (repeat of T2)
- User practice (open ended: changes in the way drivers interact with the function)
- Travel patterns (open ended: changes in driver travel patterns)

**Time 4 Questionnaire (administered at end of trial):**
- Attitudes towards target driving behaviours (repeat of T1)
- Function acceptability scale (repeat of T2)
- Perceived ease of use scales (driver ability to use function successfully with minimal effort; e.g., “The visual display was well located – Strongly disagree XXXXX Strongly agree”)

Deliverable D6.2
Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment
- Trust (open ended: situations in which driver did not trust function).
- User practice (repeat of T3)
- Travel patterns (repeat of T3)
- Function effects (effect of function on driving e.g., “Following distances – Decreased significantly XXXXX Increased significantly”)
- Perceived usefulness (measures situations in which drivers found function most useful e.g. “On highways in normal traffic”)
- Function design (open ended: driver recommendations for improving function)
- Affordability (repeat of T2)
- Social acceptability (measures driver acceptability of function to others in society e.g. “Should the function be fitted to all new vehicles?”)
- Function use (self reported misuse and abuse of function; e.g. “Used the ACC to overtake – Never XXXXX Frequently”)
- Mental workload scale (repeat of T2)

Exit Interview (administered to drivers who withdraw prematurely from study):
- Reasons for withdrawing (closed and open questions)
- Study evaluation (scales to assess driver’s study experience e.g. “Recruitment process – poor XXXXX Excellent”)

Debrief (administered to those who complete FOT):
- Overall function evaluation (open-ended questions about critical events that made driver glad/not glad to have function; passenger responses to function; feeling of safety with function; whether driver would purchase function in future
- Study evaluation (same as Exit Interview)

The questionnaires were comprised of both standardised and non-standardised items. Where possible, the former were used, including:

i. Van der Laan’s acceptability scale (within the System Acceptability Scale) [50]
ii. Arnett’s sensation seeking scale (i.e., the Personality scale) [41]
iii. Van Westendorp affordability procedure (i.e., Affordability) [51]
iv. RSME mental workload scale (i.e., the Mental Workload scale)

Further items were developed internally, where standardised measures did not exist, covering concepts such as travel patterns and attitudes towards target (function-related) behaviours. Furthermore, additional items related to acceptance were inserted, over and above van der Laan’s methodology, based on an in-depth literature review. These items were thought to influence acceptability and included perceived ease of use and usefulness. Misuse of the function was captured via a number of items submitted by individual VMCs.

3.3.2 Preparatory Activities

Special preparatory activities must be undertaken prior to analysis of the questionnaire data:

Data Quality:
- the questionnaire developed in WP4400 must be checked to ensure that it contains all questions required to test all relevant hypotheses in Annex 2A
- all instructions in the questionnaire must be clear and understandable
- all questions must be clear and understandable
deliverable D6.2
Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment

- data yielded by the questionnaire must be in a form that can be analysed
- administration of the questionnaire must be standardised across VMCs
- it must be checked that there is no missing data
- it must be checked that questions were properly answered by drivers
- it must be checked that there are no errors in the coding by analysts of answers
- it must be checked that there are no errors in database entry
- it must be checked that there are no invalid (out of range) responses.
- appropriate measures must be undertaken to “clean” data that are found to be of poor quality

Data Coding:
- For open ended questions, harmonised categories for the answers must be derived so that, as for closed response questions, the data are coded in the same way across VMCs

3.3.3 Analysis Plan – Generic Approach

A common analysis plan for the subjective data was developed to ensure that VMCs were able to analyse and report the data derived from the questionnaires in a coherent and consistent manner.

Within an Excel spreadsheet, each hypothesis was assigned a separate worksheet and, using dummy data, each VMC was provided with guidance as to which items in the questionnaire should be “dropped into the worksheet” to test each hypothesis. Where necessary, guidance on the coding of responses was provided, and an explanation regarding the items was provided in an associated document.

For example, one section of the questionnaire is titled System Use. Here, there are several questions, answered on a 5 point scale (e.g., “The driver relies on the FCW in order to perform other tasks (e.g., eating, changing radio)” – Never 0, 1, 2, 3, 4 Frequently”). Each item (i.e. question) is given a unique identifier. For example, the identifier for the above item (xxx_mis_1i4) is explained in the table below.

<table>
<thead>
<tr>
<th>Xxx</th>
<th>mis</th>
<th>1i4</th>
</tr>
</thead>
<tbody>
<tr>
<td>The VMCs were asked to insert the function name here (e.g. FCW)</td>
<td>Refers to overarching theme, here “mis” refers to misuse of the function</td>
<td>1 refers to the construct number which contributes to the theme, labelled 1, 2, 3, etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>i refers to the item number within the construct (labelled a, b, c, etc.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 refers to the time period, labelled 1-4</td>
</tr>
</tbody>
</table>

Thus, this item was recorded at Time 4, it refers to misuse of the function, it is the first construct of misuse, and this particular item is the 9th one within the section of the questionnaire titled “System Use”.

With regards to statistical testing, the coding and analysis of the standardised scales within the questionnaires replicated that reported by the original authors. An example of this is found in Annex 2C (Example 1). For example, sensation seeking scores were coded and analysed according to the procedure described in [41]. A number of different types of statistical testing can then be carried out, depending on the hypotheses in question. Sensation seeking scores can be correlated with other measures, such as acceptance, in
order to establish whether sensation seeking scores vary in line with acceptability scores. Or, participants can be categorised as either high or low sensation seekers, based on a median split, and then the groups compared across measures of acceptability etc.

Given that the questionnaires were administered at various time-points throughout the trial, some items could be analysed using repeated measures techniques, using time as an independent factor. Examples of these repeated measures include acceptability, trust and workload and there are specific hypotheses that aim to establish whether exposure to a function affects participants’ ratings. In this case, statistical techniques will be used to test the hypotheses. T-tests will be carried out where there are two time-points and Analysis of Variance where there are three or more. An example of this is found in Annex 2C (Example 2).

Non-standardised items were typically analysed descriptively. For example, Perceived Ease of Use, in Time 4, was measured using scales spanning 1 to 5, relating to the features of a particular function (e.g., “It was easy to learn how to use the function – Strongly Disagree 1,2,3,4,5 Strongly Agree”). The results are presented graphically and whilst statistical analysis was not performed, the graphs relate directly to the stated hypothesis. An example of this is found in Annex 2C (Example 3).

3.3.4 Reporting Plan

A harmonised approach has been developed for the reporting of the findings that derive from the testing of hypotheses relying on questionnaire data. In effect, the VMCs can copy and paste their data into the Excel spreadsheet developed and the graphs and summary statistics are then automatically generated. This ensures that all the graphs across functions and VMCs are in the same format, for ease of interpretation.

Annex 2C (Examples 1-3) provides examples of the types of output from the subjective data analyses.
4 Safety impacts

The purpose of the safety impact analysis is to assess the extent to which the functions being evaluated in euroFOT can be expected to alter the current crash populations in the EU27 region in terms of accidents, injuries, fatalities and potentially property damage, and then turn these numbers over to the cost-benefit analysis (CBA) in WP6500. The CBA will then estimate the costs and benefits of deploying these functions on the EU27 level.

At the core of the safety impact analysis is a subset of the hypotheses described in chapter 3 and Annex 2A. However, as these hypotheses generally are of the type “does X change in treatment compared to baseline?”, they need to be placed in the wider context of a full benefit analysis in order to help answer the question of whether safety would be improved if the evaluated functions were widely deployed in the EU 27 region. Therefore, in this chapter, the process for calculating safety benefit estimates for the safety functions in euroFOT is described.

The process has three main steps:

(1) Defining the target crash population. This involves finding out from national crash data in the countries where the functions are being evaluated, how many function-relevant crashes (i.e. crashes that the function could potentially help prevent) occur on an annual basis.

(2) Identifying changes in safety related measures between baseline and treatment. This involves testing a number of hypothesis on how various safety related metrics might change between baseline and treatment in the collected data for the functions evaluated;

(3) Interpreting what any significant changes in these metrics mean, in terms of a generalized safety impact estimate on the EU27 level. This means estimating, based on the identified changes in step 2, how the number of accidents, injuries and fatalities could be expected to change in the national crash population if the evaluated functions were to be nationally deployed, and then extrapolate those results to the rest of the EU, i.e. trying to project what would happen in the full EU27 driving population if the functions were deployed EU-wide.
The general process is illustrated above in Figure 8. Note that while the details of how this process is applied will vary somewhat between VMCs, depending on the function being evaluated and how data collection has been set up, the general procedure is intended to be the same across VMCs. An overview of the functions, the crash populations and the types of analysis to be performed is given in Table 5 below. Table 5 does not explain how to do the analysis, this is described later. In general three ways of analysing the empirical data can be used. The first is Event Based Analysis (EBA). Here the aim is to find out whether the frequency of safety critical driving situations changes when a safety function is made available to the driver. The second is Aggregation Based Analysis (ABA). Here the aim is to identify any significant changes between baseline and treatment in aggregated continuous data, such as mean speed or mean time headway. The third is Physical Risk Modelling (PRM), a simulation based analysis of vehicle conflicts. Starting conditions are sampled from FOT data and Monte Carlo simulations are then performed to explore a large range of possible situation outcomes given those starting conditions. These types of analysis are further described and exemplified in section 4.2.

In the sections following the table below, there will first be a general description of what the three steps above mean. The general description of the second step includes short summary descriptions of the three methodological approaches by which the second step will be carried out. After all three steps have been described, examples of the process based of each of the three approaches described in step two are given to illustrate in more detail how the safety impact assessment will be carried out. Last, there is a section on methodological concerns, where issues like how to avoid double counting of function effects and what to do when there are multiple functions in the same vehicle are discussed.
Table 5: Overview of the current list of possible hypotheses on changes between baseline and treatment in the collected data that could be addressed using the data collected by euroFOT. The analysis types that can be applied to test each hypothesis on the collected data is shown in the rightmost column. For a description of how to generalise the outcome of any hypothesis testing (i.e. how to use the result to estimate a general safety impact), see section 4.3 below. Note that this list covers only safety impact related hypothesis, and they are formulated to be answered by vehicle data, not questionnaire data.

<table>
<thead>
<tr>
<th>Function</th>
<th>Target Crash Population</th>
<th>Hypothesis on what might change in the experimental data when the function is made available to the driver</th>
<th>Type of analysis to be performed to test the hypothesis on the data collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC+FCW</td>
<td>Rear-end crashes</td>
<td>Using ACC+FCW, the number of forward crashes, near crashes, and incidents will decrease</td>
<td>EBA analysis of event frequencies (forward accidents and incidents) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ACC+FCW use increases over time</td>
<td>PRM modelling of risk and severity of crash involvement in car following situations with ACC+FCW on and ACC+FCW off</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ACC+FCW decreases average speed</td>
<td>ABA analysis of average speed in baseline and treatment, comparing for example mean speed with regular cruise control to mean speed with ACC+FCW.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ACC+FCW decreases the number of critical time gaps to the leading vehicle</td>
<td>EBA analysis of event frequencies (instances of time headway shorter than X) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ACC+FCW increases average time gap</td>
<td>ABA analysis of mean time headway with ACC+FCW on compared to ACC+FCW off</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Using FCW+ACC, focus on primary task (time in which the driver looks straight ahead) will decrease over time on motorways</td>
<td>ABA analysis of visual behaviour measures like percentage road centre, glance frequency, glance duration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Using ACC+FCW, frequency of drowsy</td>
<td>Eye Tracking indicators (glance freq, percent road centre, glance duration,</td>
</tr>
<tr>
<td>LDW</td>
<td>Crashes (single vehicle or multivehicle) initiated by an inadvertent lane departure</td>
<td>PERCLOS), SDLP</td>
<td>Using ACC+FCW, driver's reaction time (time to reach the brake pedal) will increase if ACC is used most of the time and decrease if only the FCW function is actually used</td>
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<td></td>
<td>The driver changes the use of ACC over time by increasing the occurrence of overriding the ACC function by using the accelerator pedal.</td>
<td>EBA analysis from footwell video of Response time when reaching for the brake pedal</td>
<td>EBA analysis from footwell video of Driver's reaction time when reaching for the brake pedal</td>
</tr>
<tr>
<td></td>
<td>Using ACC+FCW focus and level of engagement on secondary tasks will increase</td>
<td>Usage of accelerator pedal when function is active</td>
<td>EBA analysis of how often drivers are doing secondary tasks at the time of a critical event when ACC+FCW is on compared to when ACC+FCW is off. Secondary tasks classification comes from video coding of critical events measured, or are measured via surrogate (single long glance and visual time sharing based on road centre, e.g lower PRC).</td>
</tr>
<tr>
<td></td>
<td>LDW decreases/mitigates lateral incidents, near-crashes, and accidents</td>
<td>EBA analysis of event frequencies (lateral accidents and incidents) per mileage/time driven/no of drivers</td>
<td>EBA analysis of event frequencies (lateral accidents and incidents) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td></td>
<td>LDW influences lateral driving performance</td>
<td>EBA analysis of event frequencies (number of passing the lane markings) per mileage/time driven/no of drivers</td>
<td>EBA analysis of event frequencies (exceeding a certain offset to the lane markings) per mileage/time driven/no of drivers</td>
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<td></td>
<td>LDW increases the use of turn indicators in lane change situations</td>
<td>Relation between lane change occurrences (measuring position in lane) and use of turn indicators compared in LDW ON / OFF situations</td>
<td>ABA analysis of changes in steering wheel angle/velocity/frequency of movement in baseline (no LDW) compared to treatment (LDW available)</td>
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<td></td>
<td>LDW increases usage more and more over time</td>
<td>Time series based EBA analysis of LDW activation occurrences (total number of activations per X hours of driving)</td>
<td>Time series based EBA analysis of LDW activation occurrences (total number of activations per X hours of driving)</td>
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<tr>
<td><strong>Deliverable D6.2</strong></td>
<td><strong>Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment</strong></td>
<td></td>
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<tr>
<td><strong>Time series based ABA</strong></td>
<td><strong>EBA analysis of driver response in lane relevant lane exceedance situations</strong></td>
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<td><strong>LDW warning</strong></td>
<td><strong>EBA analysis of visual behaviours related to drowsiness (Eye closure time, eye closure frequency, etc) and vehicle behaviours related to degraded control (Steering wheel entropy, severe corrections, etc), comparing baseline and treatment</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>LDW decreases drowsy driving</strong></td>
<td><strong>PRC history in combination with LDW warnings</strong></td>
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<tr>
<td><strong>BLIS</strong></td>
<td><strong>Blis decreases the number of crashes, near crashes, incidents</strong></td>
<td><strong>EBA analysis of event frequencies (lane change accidents and incidents) per mileage/time driven/no of drivers</strong></td>
<td></td>
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<tr>
<td><strong>BLIS</strong></td>
<td><strong>Blis reduces use of turn indicator to change lanes</strong></td>
<td><strong>EBA analysis of the frequency of lane change indicator use when on multilane roads in baseline vs. treatment</strong></td>
<td></td>
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<tr>
<td><strong>IW</strong></td>
<td><strong>Iw decreases the number of crashes, near crashes, incidents</strong></td>
<td><strong>EBA analysis of event frequencies (drowsiness and prolonged distraction related accidents and incidents) per mileage/time driven/no of drivers</strong></td>
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<tr>
<td><strong>IW</strong></td>
<td><strong>Iw increases lateral driving performance</strong></td>
<td><strong>EBA analysis of event frequencies (number of passing the lane markings) per mileage/time driven/no of drivers</strong></td>
<td></td>
</tr>
<tr>
<td><strong>IW</strong></td>
<td><strong>Iw decreases drowsy driving</strong></td>
<td><strong>EBA analysis of changes in steering wheel angle/velocity/frequency of movement in baseline (no LDW) compared to treatment (LDW available)</strong></td>
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<tr>
<td>SL/CC</td>
<td>IUW increases usage more and more over time</td>
<td>Time series based EBA analysis of IUW activation occurrences (total number of activations per X trips in treatment)</td>
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<td>-------</td>
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<td>---------------------------------------------------------------------------------------------------------------</td>
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<tr>
<td>SL/CC</td>
<td>Rear-end crashes</td>
<td>Using SL (resp. CC), the number of forward crashes, near crashes, and incidents will decrease</td>
<td>EBA analysis of event frequencies (forward accidents and incidents) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td>SL/CC</td>
<td>Time series based EBA analysis of IW activation occurrences (total number of activations per X trips in treatment)</td>
<td>PRM modelling of risk and severity of crash involvement in car following situations with SL on, CC on, and SL or CC off.</td>
<td></td>
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<tr>
<td>SL/CC</td>
<td>Using SL (resp. CC) reduces speeding occurrences</td>
<td>EBA analysis of event frequencies (Instances of time with speed larger than legal speed, with more than 10 sec duration) per mileage/time driven/no of drivers</td>
<td></td>
</tr>
<tr>
<td>SL/CC</td>
<td>EBA analysis of event frequencies (hard deceleration events) per mileage/time driven/no of drivers</td>
<td>Using SL (resp. CC) will increase the occurrences of strong jerks</td>
<td></td>
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<tr>
<td>SL/CC</td>
<td>EBA analysis of event frequencies (hard deceleration events) per mileage/time driven/no of drivers</td>
<td>SL (resp. CC) decreases the number of critical time gaps to the leading vehicle</td>
<td></td>
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<tr>
<td>SL/CC</td>
<td>Time series based EBA analysis of SL (resp. CC) activation occurrences (total number of activations per X hours of driving)</td>
<td>Using SL (resp. CC) use increases over time</td>
<td></td>
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<tr>
<td>SL/CC</td>
<td>Time series based ABA analysis of SL (resp. CC) activation time (total time in use per X hours of driving)</td>
<td>Using CC, driver’s reaction time (time to reach the brake pedal) will increase</td>
<td></td>
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<tr>
<td>SL/CC</td>
<td>Time series based ABA analysis from footwell video of total time with foot positioned on the brake pedal per X hours of driving, with CC on and SL or CC off.</td>
<td>Using CSW, the mean curve entrance speed for speeds above speed limit will be reduced</td>
<td></td>
</tr>
<tr>
<td>CSW</td>
<td>CSW Loss of control due to high speed in curves</td>
<td>EBA analysis of curve entrance speed selection in baseline and treatment</td>
<td></td>
</tr>
<tr>
<td>FEA</td>
<td>No particular crash type</td>
<td>No specific safety related hypothesis posted (i.e. no posited link between reduced fuel consumption and crash</td>
<td></td>
</tr>
</tbody>
</table>
4.1 Step 1. Defining the target crash population

The first part of the safety benefit analysis is fairly straightforward. It involves defining the target crash population, i.e. the set of crashes (including the associated set of injuries and fatalities) which a particular function is intended to, and capable of, preventing. For example, for Forward Collision Warning (FCW) this is the set of rear end crashes which occur within the function’s operational scope (certain ego vehicle speeds and approaching speeds to lead vehicle). For Lane Departure Warning (LDW), this is the set of crashes which start with an unintentional lane departure, and again, which are within the function’s operational scope (visible lane markers, above certain ego vehicle speed, etc.).

Once the target crashes have been identified, data describing the crash circumstances should be cross tabulated in order to identify the most typical conditions under which these crashes occur. The rationale for this step is to provide a filter, or set of limitations, in the analysis of the actual FOT data. In principle, any ADAS driven change which occurs outside this envelope of crash typical circumstances will not affects the safety impact (since by definition no relevant crashes occur outside those conditions). Leaving those data portions out of the analysis thus both saves time and effort, as well as focuses the analysis.

To provide the best fit with FOT data, the data source used for defining the target population should typically be a national crash database covering the country or countries where the function is being evaluated. It should be stressed that some modifications to the crash types used for that country/countries probably will be necessary, as the crash typology used to extract relevant crashes needs to be comparable to those used in other similar national databases (if not, the scaling up of potential impact to the European level becomes a very difficult task).

In euroFOT, the identification of the target crash population will be based on the work of many previous and ongoing projects which already have addressed this issue from various angles. In particular, it is foreseen that the crash typology developed in the ASSESS project [6] will provide a good starting point. The ASSESS typology has the advantage of being set up to uniformly select crashes in Swedish, British and German crash data, which matches the countries where many of the euroFOT ADAS are being evaluated. Moreover ASSESS has made an estimate of the costs and injuries associated with each crash type. In principle the ASSESS work can be used as the basis for projecting any identified crash risk changes due to ADAS presence onto injuries (including fatalities) and economical costs.

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2 Intended is here to be understood as the set of crashes that function developers intend the system to address. While there also may be unintended effects of a safety system of either positive or negative nature, the evaluation of these is given a lower priority and will be carried out only once the intended effects are assessed given that resources for such work is still available.
4.2 Step 2. Identifying changes in safety related measures between baseline and treatment

The second part of the methodology is quantifying the difference which the presence of an ADAS makes, i.e. quantifying any changes in crash risk between baseline (no ADAS) and treatment (ADAS present). While literature provides several examples of methods dealing with obtaining safety impacts, e.g. the methods developed in AIDE [40] and eIMPACT [39], none of these methods is fully suited to be used on FOT data, and thus a partially new methodology had to be developed for euroFOT.

In terms of how this methodology is set up, it is first important to recognize that the number of actual crashes occurring during euroFOT will be very limited. Even when hundreds of drivers are being observed during a full year, the statistical likelihood of a crash occurring is low. This means that the simplest and most direct measure of change in crash risk, i.e. the number of crashes which occur with and without the ADAS, will not be available, at least not in sufficient numbers to reliably quantify a difference between baseline and treatment. Also, the likelihood of injuries and fatalities occurring in the FOT is even smaller than for accidents.

Thus, rather than using actual crash and/or injury frequencies, other indicators of change in crash risk have to be defined and used, such as the frequency of safety critical events or changes in driver behaviours that are known to be crash causation related. In other words, to determine whether a particular ADAS is successful in preventing a certain crash type, one must first develop an understanding of why that crash type occurs. Once that understanding is in place, a measure of change that captures the function's impact on that particular crash causation mechanism(s) can be defined.

For example, many rear end crashes are thought to occur due to unexpected lead vehicle braking while the driver is visually distracted from the forward roadway [13]. In relation to this crash causation mechanism, a FCW function can be understood as a tool for interrupting the driver's state of distraction and alerting him/her to the braking of the lead vehicle. If FCW is successful in this regard, one would expect among other things a decrease in the number of panic braking events for drivers of vehicles equipped with FCW. The frequency of panic braking events can therefore be used as an indicator of change in crash risk due to the presence of FCW.

Another way of getting at the same crash causation mechanism of unexpected lead vehicle braking events is to increase the available safety margins, thus making sure the driver has sufficient time for detection and action once the lead vehicle brakes. This is the intended function of Adaptive Cruise Control (ACC) – at least according to the system design at Volvo/Ford –, which when activated (and within certain limits) precisely regulates the time headway to the lead vehicle. By operating in this manner, ACC might help the driver avoid the risk of inadvertently ending up in a situation where s/he is following close to a lead vehicle that may brake and being distracted at the same time (i.e. ACC negates the following too close aspect of the problem). To evaluate whether ACC is successful in increasing the safety margin this way, another measure of change than the frequency of panic braking is required, such as whether there is a change in average following time, or the total driving time spent at time headways below one second.

To facilitate the process of identifying changes between baseline and treatment in the collected euroFOT data, a number of hypotheses on how various safety related measures may be impacted by ADAS presence have been formulated. Testing whether these hypotheses hold or not essentially forms the core of this second step of the methodology (i.e. identifying function driven change in the collected data). However, as these hypotheses already have been described in Chapter 3 and Annex 2 they will not be further reiterated here. Rather, the description below focuses on the general ways in which those hypotheses can be broken down to a level where it becomes possible to actually query the database and get an answer.
Depending on the function being analysed and the hypothesis to be answered (i.e. how the function’s influence on some crash causation mechanisms is conceived), the three principal ways of analysis (EBA, ABA, PRM) will be applied accordingly. These methods are briefly described below and in sections 4.4, 4.5, and 4.6 more elaborate descriptions and examples of application can be found.

A word of caution before going into the analysis types; the relationship between an identified change between baseline and treatment and accident involvement is neither straightforward nor well established. This poses a challenge for the analysis of an essentially non-crash data set like euroFOT, regardless of which approach to querying the data (ABA, EBA and PRM) is used. Ideally one would select and compare only events and/or aggregate measures which are known to be predictive of actual crash involvement, i.e. where it is legitimate to infer that a particular change in what is measured corresponds to a particular change in crash frequency. However, the science of investigating and establishing these relationships has yet a long way to go before being fully mature, at least for FOT type data. In other words, to project a change in crash data based on a mainly non-crash data set, a number of assumptions has to be made, and thus the validity of the projection will rest on the validity of those assumptions. For a more extensive discussion of this topic, see subsection 4.7.1.

Events Based Analysis (EBA)

The basic principle of EBA in a FOT context is to identify relatively short time segments (events), thought to be predictive of crash involvement, and then compare the frequency of these in baseline (no ADAS present) and treatment (ADAS present). Examples of events are actual crashes, as well as situations where the driver performs a violent evasive manoeuvre [13], i.e. where the distance in time and/or space from an actual crash is very small (near crashes/incidents). These events can be identified retrospectively in the driving data, together with interaction/confounding factors such as road type, speed limit, traffic conditions, other functions etc.

EBA analysis is primarily relevant for answering hypotheses on the extent to which a particular ADAS reduces the frequency of these time discrete events. This includes events directly related to loss of control, such as crashing into a lead vehicle (FCW), unintended lane departure (LDW) and commencing a lane change when the adjacent lane is not empty (BLIS). It can also be applied to events more indirectly related to loss of control, such as deciding to continue to drive when driving capacity is severely degraded (IW) and various forms of speed selection (Speed regulation systems (SRS) or Curve Speed Warning (CSW)). As long as the ADAS influence on driver performance can be described using the occurrence of discrete events, EBA analysis is applicable. Examples of previous studies where EBA analysis has been applied include [12], [13], [14], [17] and [18].

Aggregation Based Analysis (ABA)

Aggregation based analysis (ABA) is a process for defining the change between baseline and treatment in terms of how driving performance changes over longer periods of time. This type of analysis is primarily relevant for answering hypotheses on for example whether the average following distance or travel speed decreases as a function of ADAS presence.

It follows that ABA analysis applies primarily to functions which are intended to change certain driver performance measures over time, such as fuel consumption (FEA), time headways to the lead vehicle (ACC), speed selection for curves (CSW) or speed selection in general (SL/CC).
Physical Risk Modelling (PRM)

Finally, Physical Risk Modelling (PRM) is a simulation based approach. In PRM the starting conditions are sampled from FOT data, and Monte Carlo simulations are then performed to explore a large range of possible situation outcomes given those starting conditions. PRM can thus be defined as a simulation version of EBA, and in euroFOT it is going to be applied to Adaptive Cruise Control (ACC), which often is hypothesized to have a conflict reducing effect.

Choice of method

Note that EBA, ABA and PRM are complementary forms of analysis which explore the impact of an ADAS from different angles, based on how the ADAS safety impact is conceptualized in terms of influence on crash causation (i.e. which hypothesis are selected to being tested for the function). For ACC/FCW for example, a potential increase in average time headway is best investigated with an ABA analysis, while a potential decrease in the number of lead vehicle conflicts is best investigated with an EBA or PRM type of analysis. Exactly which methods will be used at each VMC has yet to be decided, as some exploratory work is necessary when the actual data collection has finished in order to determine what can be done given the size and quality of the available data. However, if more than one type of analysis is performed on the same ADAS, it is important to remember not to unconditionally sum these effects (see section 2.6), as any found effects presumably reflect changes in the same underlying causation mechanisms.

Hypotheses testing

During step 2, all safety hypotheses – except for the ones that have to do with the number of crashes – can be tested for the FOT data.

4.3 Step 3. Interpreting what any identified change between baseline and treatment means in terms of a generalized safety impact on the EU27 level

The third part of the methodology is taking the quantified differences between baseline and treatment and calculating what it can mean in terms of reducing the full crash population on a EU27 wide level. This is done in three steps. The first is to decide which of the identified differences are to be used for the actual prediction. The second is to calculate the reduction in crashes on some level of detail. The third is to extrapolate those results to the EU27 wide crash population level. Below, these parts are addressed in turn.

4.3.1 Step 3a: Statistically testing size and significance of identified effects

First, there is the issue of size and significance of an identified difference between baseline and treatment, or between some other comparison conditions (like at various times during treatment). To test this, many different methods are available, depending on the data analysed and the hypothesis to be addressed. For ABA data analysis, which typically becomes a comparison of means between baseline and treatment, or changes in means over time as drivers use a particular function more and more, various types of variance and regression analysis can be applied, such as ANOVA and linear regression models. The main challenges for statistical ABA data analysis are to define how baseline segments should be selected, as well as to understand what should be considered covariates and confounders.
Statistical analysis for ABA will use paired comparison to control for the different drivers' behaviours. Further, comparison of performance indicators may not be limited to their mean value but, depending on the sample size, the comparison may be extended to the distribution of the performance indicator. For example, the hypothesis “ACC increases mean speed” can be tested more robustly by comparing different quartiles (e.g. 25%, 50%, and 75%) of the distribution of mean speed in treatment and baseline condition. In some cases, multiple observations will be an issue. For instance, when querying for a specific condition which may be satisfied in a trip in a number of occasions, the SQL database will return segments of data which are dependent observations. To avoid bias by dependent observations a bootstrap procedure may be employed. Specifically, statistical significance will be tested against a distribution created by multiple resampling of the database so that bias from dependent observations can be eliminated.

When it comes to analysing EBA data, i.e. to compare event frequencies in baseline and treatment, many different methods described in [34] are available. The simplest form of comparison is to make a contingency table by counting the frequency of events in baseline and treatment conditions (based on some form of exposure normalisation, such as the number of events per driving hour) for each driver to understand, whether ADAS presence causes a change in event frequency. For example, consider the following contingency table:

<table>
<thead>
<tr>
<th></th>
<th>Baseline (function “not available”)</th>
<th>Treatment (function “available”)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of crashes (or safety events)</td>
<td>N1</td>
<td>N2</td>
</tr>
<tr>
<td>Km’s driven (or duration)</td>
<td>T1</td>
<td>T2</td>
</tr>
<tr>
<td>Crash (or events) rate</td>
<td>( \Pi_1 = \frac{N_1}{T_1} )</td>
<td>( \Pi_2 = \frac{N_2}{T_2} )</td>
</tr>
</tbody>
</table>

The risk change due to function presence can then be quantified and statistically tested using both relative risk (RR) \( \frac{\Pi_1}{\Pi_2} \) and/or the odds ratio (OR) \( \frac{(1-\Pi_1)}{(1-\Pi_2)} \frac{\Pi_1}{\Pi_2} \). OR approximates RR when \( \Pi_1 \) and \( \Pi_2 \) are small.

Logistic regression

Statistical models are an alternative method for describing the relationship between an outcome variable and a set of explanatory variables. In EBA, the outcome variable is from a binary distribution with two possible values:

\[
Y_{ij} = \begin{cases} 
1 & \text{if event} \\
0 & \text{if not} 
\end{cases} \quad i = 1, \ldots, I \ ; \ j = 1, \ldots, T_i
\]

Where \( I \) is the number of drivers and \( T_i \) is the number of observations for the driver \( i \). Logistic regression is a form of statistical modelling that is often appropriate for binary outcome variables. Assume \( Y_{ij} \) follows a Bernoulli distribution with parameter \( p_{ij} = P(Y_{ij} = 1) \) where \( p_{ij} \) represent the probability that the event occurred for observation \( Y_{ij} \). The relationship between the event probability \( p_{ij} \) and the set of factors is modelled through a logit link function with the following form:

\[
\text{logit}(p_{ij}) = \log \left( \frac{p_{ij}}{1 - p_{ij}} \right) = X_{ij} \beta
\]

Eq. (1.1)
Where $\mathbf{X}_{ij}$ the vector of explanatory variables and $\mathbf{\beta}$ is the vector of regression parameters. The odds ratio defined previously with a contingency table correspond to the exponential of the regression parameters. For instance, $\exp(\beta_k)$ is the multiplicative effect on the odds of a 1-unit increase in $X_k$ at fixed levels of other $X_j$ [31].

The variance function is $\text{Var}(Y_{ij}) = \mu_{ij}(1 - \mu_{ij})$ where $\mu_{ij} = p_{ij}$. The vector of regression parameters $\mathbf{\beta}$ is estimated by the method of maximum likelihood and the estimator $\hat{\mathbf{\beta}}$ is solution of the likelihood equations (score equations) obtained by derivates of the log-likelihood function (denoted $l$) with respect to $\mathbf{\beta}$:

$$U(\mathbf{\beta}) = \sum_i D_i' \Sigma_i^{-1} (Y_i - \mu_i) = 0$$  
**Eq. (1.2)**

Where $D_i = \partial \mu_i / \partial \mathbf{\beta}$ (diagonal matrix), $\Sigma_i = \text{diag}(\text{Var}(Y_{ij}))$ is the diagonal matrix of the variances, $Y_i$ is the vector of observations $Y_{ij}$ and $\mu_i$ is the vector of $\mu_{ij}$. The ordinary logistic regression assumes independent observation and so the score equations are called independence estimating equations (IEE) [37] and are solved by iterative methods like Fisher’s scoring algorithm or Newton-Raphson method. The asymptotic properties of the independence estimator $\hat{\mathbf{\beta}}$ are well known: $\hat{\mathbf{\beta}}$ is consistent and $\hat{\mathbf{\beta}} \rightarrow \mathcal{N}(\mathbf{\beta}, I_0^{-1})$ where $I_0 = \sum_i D_i' \Sigma_i^{-1} D_i$ is the Fisher-information matrix.

A drawback of contingency tables and ordinary logistic regression is that they assume observations to be independent of each other. This assumption does not suit FOT data very well, as it will contain unavoidable driver-specific correlations (i.e. some drivers will experience more events than others). The standard errors from the ordinary logistic regression are then biased because the independence assumption is violated [35]. To study interacting/confounding factors and to account for these driver specific correlations, more sophisticated statistical models need to be applied.

These models are generalizations of the linear model which have been adapted to a binary outcome, something which suits the EBA analysis division of events into baseline and treatment events well. These models include additional parameters to deal with correlations, and confounding factors are viewed as explicative variables that can be used to predict event probability.

One such model is the “Generalized Estimated Equations” (GEE) model, originally developed to model longitudinal data by [36], which assumes that observations are marginally correlated. Another such model is “Generalized Linear Mixed Models” (GLMM). Similar to the GEE model, GLMM assume correlated observations for the same driver. In addition, GLMM also assumes that there is a random effect associated with each individual driver (i.e. one driver can be associated with higher and another with lower risk of event involvement). This has the additional advantage of allowing controlling for a small population of drivers being involved in a large proportion of safety events, something which indeed may become an issue [34]. Both GEE and GLMM models can also accommodate multiple risk factors, which allow those factors to be evaluated simultaneously. Indeed, this capability may also be used to evaluate different functions in use at the same time or at different times but with possible interactions.

**Generalized Estimating Equations**

Marginal models based on the concept of generalized estimating equations (GEE) were introduced by [36] for analysis of longitudinal data. They are an extension of generalized
linear models (GLM) and correspond to quasi-likelihood models for non-independent observations [32]. Indeed, the GEE approach does not specify a likelihood function (based on the independence of the observations) but uses a quasi-likelihood for which no proper probabilistic models exist.

From the previous section, when the assumption of independent observations is verified (i.e. $\text{Corr}(Y_{ij}, Y_{ij'}) = 0$), logistic model is written as (1.1). However when observations are correlated (i.e. $\text{Corr}(Y_{ij}, Y_{ij'}) \neq 0$), a working variance-covariance matrix is specified as follows:

$$\Sigma_i = A_{ij}^{1/2} R_{ij}(\alpha) A_{ij}^{1/2}$$  \hspace{1cm} \text{Eq. (1.3)}

Where $A_{ij}$ is the diagonal matrix of the variances $\text{Var}(Y_{ij})$ and $R_{ij}(\alpha)$ is the working correlation matrix described by an additional parameter $\alpha$. Thus the GEE approach treats the correlation between observations as a nuisance and different working correlation structures can be specified:

- **Independent**: $\text{Corr}(Y_{ij}, Y_{ij'}) = 1$ for all $j, j'$.
  Assume zero correlations between repeated observations.

- **Exchangeable**: $\text{Corr}(Y_{ij}, Y_{ij'}) = \{\begin{array}{ll} 1 & \text{if } j = j' \\ \alpha & \text{if } j \neq j' \end{array}$.  
  Assume that all observations are equally correlated.

- **Autoregressive (AR1)**: $\text{Corr}(Y_{ij}, Y_{ij'}) = \alpha^{|j' - j|}$.  
  Use for time series analysis. Assume that observations closer together in time may tend to be more highly correlated.

- **Unstructured**: $\text{Corr}(Y_{ij}, Y_{ij'}) = \alpha_{jj'}$ if $j \neq j'$.  
  This structure is the most general but requires more parameters to estimate. Furthermore, this structure cannot be selected if the number of observations per subject is not constant.

Then the estimator $\hat{\beta}$ of the vector of regression parameters is solution of the following quasi-likelihood equations called generalized estimated equations (GEE):

$$\sum_i D_i' \Sigma_i^{-1}(Y_i - \mu_i) = 0$$  \hspace{1cm} \text{Eq. (1.4)}

Where $\Sigma_i$ is defined by (1.3). If the identity matrix is used as working correlation matrix, the GEE (1.4) are reduced to the IEE (1.2). The estimate of $\beta$ is achieved using an iterative process: Fisher modified-algorithm (where the term "modified" means that $\Sigma_i$ is used instead of the true variance matrix denoted $S_i$).

This working variance-covariance matrix is generally different of the true variance-covariance matrix $S_i$. But the principal interest of the GEE approach is the robustness of the estimate even if the assumed working correlation is misspecified. Also the estimator $\hat{\beta}$ is consistent and the variance of $\hat{\beta}$ is estimated using a ‘sandwich estimator’ instead of the Fisher information matrix. Under mild regularity conditions,
Finally, the GEE approach allows to model binary outcomes that arise from longitudinal data without requiring the joint distribution. Thus, because of the lack of likelihood, the GEE are considered as an estimating method rather than a model [31].

**Generalized Linear Mixed Models**

Another approach for modelling correlated data is "Generalized Linear Mixed Models" (GLMM). The GLMM model introduces a random effect specific to each subject whereas the GEE approach models the marginal distributions by treating correlation as a nuisance parameter. Thus, the outcome variable is modelled conditionally on these random effects. One driver can be associated with higher and another with lower risk of event involvement. Therefore the inference is individual (subject-specific approach) in contrast to marginal models that model the average population (population-averaged approach) (Hu et al., 1998).

Generalized linear mixed models (GLMM) extend generalized linear models (GLM) to include random effects. Thus the random-effects logistic model is written as follows:

\[ \text{logit}[P(Y_{ij} = 1|u_i)] = X_{ij}'\beta + z_{ij}u_i \]  

Eq. (1.5)

Where \( X_{ij} \) and \( \beta \) are defined as in the ordinary logistic model, \( u_i \) is the vector of random effects associated with subject \( i \) and \( z_{ij} \) is the corresponding design matrix. The estimate of \( \beta \) is performed by approximation and then maximizing the marginal likelihood. Many methods have been developed to do this like Gauss-Hermite quadrature methods, Penalized Quasi-Likelihood (PQL) or Bayesian approaches.

A special case of the model (1.5) is the random-intercept logistic model with univariate random effect and \( z_{ij} = 1 \). This special case is also called logistic-normal model [31]. Indeed, the random variables \( \{u_i\} \) are independent and are usually assumed to be distributed as \( \mathcal{N}(0, \sigma^2) \). Thus, each random effect \( u_i \) is associated with driver \( i \) and the value of \( u_i \) is related to the probability of driver \( i \) being involved in a safety event [34]. Furthermore, the estimate of the standard deviation \( \sigma \) of the random intercept indicates the degree of heterogeneity of the population.

Guo and Hankey [34] arrive at consistently different results with the two methods. Which model is preferred will be determined later; this depends on the assumptions that will be made about the data and the nature of events. This will be presented in Deliverable 6.4 which contains the results of the safety impact assessment.

### 4.3.2 Step 3b: Impact on the national level

If a significant difference between baseline and treatment has been established for an ADAS in terms of a risk indicator (for example, there may be a statistically significant reduction of 20% in the frequency of near crashes, or a statistically significant 10 km/h reduction of mean travel speed), the next step is to make an impact estimation based on that difference. This means that one has to interpret what the identified difference actually means in terms of how the target crash population can be expected to change if the function is widely deployed. This impact estimate should first be carried out for the national level, i.e. for the country in which
the function is being evaluated. Next, the national impact should be projected onto a wider EU27 scale (Step 3c below). This two-step approach is chosen because when selecting which part of the FOT data to look for changes in (see Step 1 above), crash conditions are a very relevant input (along with function limitations). For a best fit with the data collected, it makes sense to use crash conditions from the country where each respective system is being evaluated (i.e. not use typical Dutch crash conditions to select relevant portions of Swedish FOT data). Once the national analysis is done, the effect of a comparable relative change in other countries can be assessed.

The national impact estimation can be carried out at various levels of detail. The least detailed approach is to apply the identified change to the whole target crash population. For example, if the frequency of FCW relevant near crashes turns out to be 20% lower in the treatment phase, one might use this to predict a 20% decrease in FCW relevant crashes and injuries if all vehicles were equipped with FCW.

A more detailed version of the same thing would be to first calculate the impact for individual conditions in the target crash population, and then sum up the total impact. For example, if there are 2000 rural and 3000 urban FCW relevant crashes in the target crash population, the analysis might find that while the near crash reduction ratio is 25% for urban environments its only 17% for rural roads. In this case, the total safety impact would be calculated for urban and rural roads individually before summing up, i.e. the potential reduction in crashes would be 0.17*2000 + 0.25*3000/ 5000 = 21.8%.

While the more detailed approach naturally is preferable, it also requires a larger set of events to be meaningful, since the number of events per condition quickly shrinks when one the list of conditions grows longer. Thus one has to balance the desired level of detail in the impact assessment with minimum requirements on how many events per condition are needed to test for statistically significant differences between baseline and treatment.

This type of detailed impact assessment can also be used for the injury/fatality reduction calculations. For example, rather than assuming a general decrease in the set of injuries and fatalities that is associated with the target crash population, it is possible to assign crash severity levels based on the posted speeds for which the target population crashes occur, on the assumption that a higher posted speed generally implies higher initial vehicle speeds, and thus more severe injuries in case of a crash. A 15% reduction in near crashes would thus predict higher injury prevention at the 90 km/h level than the 50 km/h level.

4.3.3 Step 3c: Impact on the EU27 level

For this step, the idea is to take the national impacts as identified above and the use the eIMPACT safety spread sheet to project these numbers onto a wider set of European countries. The eIMPACT spread sheet contains six generic crash types and numbers for these crash types in terms of frequencies and injury levels associated with them for almost all current EU countries. To extend a national impact to the EU level, one thus first has to map the national target crash population for the assessed function to the eIMPACT crash types, and then calculate what can be expected for each country in terms of accident and injury reduction if they were to be reduced with the same proportions as the national crash data above.

For example, if the national impact prediction for a function evaluated in Sweden says that 20% of forward crashes will be avoided if the function is widely deployed, then one has to calculate what a 20% reduction of forward crashes in the other 26 EU means in terms of accident and injury numbers. The eIMPACT spread sheet contains the crash types and crash numbers necessary for doing this, and while parts of the spread sheet may need updating with the latest numbers, it is foreseen that it could be used with relatively few modifications.
Hypotheses testing

After step 3, the safety hypotheses that have to do with the number of crashes can be tested.

4.4 EBA example – FCW/ACC

The euroFOT EBA process follows the three steps described above, i.e. selection of target crash population, identifying any changes between baseline and treatment, and then interpreting what those changes mean in terms of a national a EU 27 safety impact. The part which is unique to EBA is how the second step is carried out. There one first identifies all events which are relevant to evaluate the safety function’s performance within the relevant portions of the total driving data, i.e. all potentially “threatening” situations, whose development and/or existence can be associated with the target crash population and which the function may help to resolve.

This first identification should cast a rather wide net, to make sure a large pool of events is selected for further analysis. For example, one way to identify FCW relevant rear-end conflict events would be to locate all events where FCW has issued a warning. Another way would be to use some public FCW-algorithm (see for example [48]). For some functions, criteria other than the warning given (whether identified by proprietary or public algorithm) may be more appropriate. For example, the conflict definition based on range over range-rate used by Wassim Najm [8] to identify longitudinal conflicts in several studies may be the most relevant one for ACC.

This “pool” of candidate events will contain a relatively large number of events, but obviously not all will carry the same weight in terms of relevance and severity when it comes to establishing a safety function’s crash preventive capabilities. They therefore need to be subdivided according to some severity scale or classification function. First, and perhaps obviously, one important dividing line goes between crashes and non-crashes. Comparing baseline and treatment by counting crashes is quite straightforward, and a more refined comparison based on assigning the crashes relative weights is also comparatively easy, i.e. actual crashes can be classified in severity terms based on the resulting level of damage to property and/or people involved. For events that do not result in a crash, counting their frequency and sorting them according to severity within that group of events, is also straightforward once a clear definition exists. For example, all panic braking events could be severity ranked based on whether brake duration exceeds 0.5s, 1.0s, and 1.5s respectively.

The starting point for the severity classification will be the nine categories of severity ranking used in SeMiFOT [18]. Those categories in turn largely overlap with the severity categories used in the VTTI 100 car study. In the example in Figure 9 below, the nine categories of severity ranking used in SeMiFOT are listed, from 1: Non-Conflict to 9: Fatal Crash. Those in turn largely overlap with the severity categories used in the VTTI 100 car study. Note that while the categories are presented as “digital” (i.e. either one event belongs to the category or it does not), it is also possible to take a group of events that fall within one severity category and again rank them for order. For example, a group of property damage only events could be ranked within the group based on for example repair cost, and a group of near crashes could be internally ranked based on for example brake intensity (how hard and long does the driver brake to avoid the collision). This type of in-group ranking is particularly interesting for further investigating the relationship between the how the event is defined its relationship to actual accident causation (given that the category is not actual crashes of course).
To illustrate the EBA process, an applied example of EBA analysis for a Forward Collision Warning / Adaptive Cruise Control function deployed in Sweden is described below. The example comes from Volvo Cars, who are evaluating a FCW/ACC function in the Gothenburg area of Sweden. The example is based on the initial driver data collection. The example data set consists of 8000 ~hours of driving, of which 4549 hours were in baseline and 3920 in treatment. As this comprises only about 10% of all the data that will be collected from those drivers, and as drivers are not uniformly represented in baseline and treatment for this sample, it has to be stressed that the example is entirely tentative. All numbers (except the size of the target crash population) will be subject to revision once the full dataset has been collected and analysed.

4.4.1 Step 1. Defining a target crash population

To select a relevant crash population, data from STRADA was used. STRADA is a publicly available database that contains all police reported and most hospital reported traffic accidents that occur in Sweden. In order to find a relevant target population, data from the years 2005 to 2008 were compiled for analysis. From the total set, a slightly modified version of the ASSESS crash type described above was used to select relevant crashes. This included all passenger car crashes where the two vehicles were travelling in the same lane and direction when the front of one vehicle struck the rear of the other vehicle. The original ASSESS type was extended to also include situations when the car strikes a vehicle that is waiting to turn or turning (as these otherwise would be subsumed under the intersection crash type in ASSESS). The annual Swedish averages, cross-tabulated for the most important traffic environment conditions, are shown below in Table 7.

Table 7: Estimated annual average accident frequencies for FCS / ACC relevant crashes in longitudinal traffic for Sweden, based on STRADA data collected in 2005-2008. Highlighted cells represent ~92% of all crashes
### 4.4.2 Step 2. Identifying any changes in safety relevant events between baseline and treatment

In this step, a pool of crash relevant events was selected from the driving data by successive filtering steps. To find the first initial set of candidate crash relevant events, the simplest solution possible was used, i.e. all situations where FCW had issued a warning or were used to flag such candidate events. This process works because in baseline, all forward collision warnings were “silent”, i.e. they were logged but not communicated to the driver.

Next, these candidate events were filtered in order to single out what could be called “true” near crash events (note that there were no actual crashes in this data sample), i.e. events where a real crash was more or less imminent and where the driver can be expected to have benefited from being alerted to this fact by the ADAS when in the vehicle.

In terms of filter criteria, as can be seen above in the target crash population table, very few crashes occur at speed limits below 50 km/h. Thus, first all events occurring at posted speeds below 50 km/h were taken away. Next, all events where the driver already had started to brake when the warning was given were excluded, on the assumption that getting a warning in that situation does not affect situation outcome. Last, all events where the maximum brake pressure during the event was above the 10\textsuperscript{th} percentile of the logged maximum brake pressures (thus excluding soft braking events), and where Time\_To\_Collision (TTC) at max brake pressure was less than 1 second (i.e. where the vehicles were close in time to colliding before the driver was comfortable with releasing the brake) were counted. Applying these filters resulted in an outcome of 12 events (8 in baseline and 4 in treatment). Note that other types of filters might be used in the final analysis. Note also that this analysis was based on approximately 10\% of what in the end will become the full database, so while this set of events is very small, the number of events in a final analysis would be substantially larger.

### 4.4.3 Step 3. Interpreting what the difference between baseline and treatment means

The final step is to interpret this difference between baseline and treatment in terms of influence on the target crash population. First, there is the issue of size and significance of an identified difference. Here the simplest form of comparison is made, i.e. a contingency table based on the frequency of events in baseline and treatment conditions, normalised by the total number of driving hours in baseline and treatment. In Table 8 below, this example data are shown, along with calculations of odds ratio and relative risk. However, as this example represents only a small and biased portion of what will be the final dataset, the significance testing is not performed in order to avoid confusion with later, more definitive results.

<table>
<thead>
<tr>
<th></th>
<th>Posted speed (kph)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td><strong>Urban</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dry</strong></td>
<td>9</td>
<td>291</td>
</tr>
<tr>
<td><strong>Not dry</strong></td>
<td>5</td>
<td>174</td>
</tr>
<tr>
<td><strong>Outside</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dry</strong></td>
<td>15</td>
<td>361</td>
</tr>
<tr>
<td><strong>Not dry</strong></td>
<td>9</td>
<td>192</td>
</tr>
<tr>
<td><strong>Rural</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dry</strong></td>
<td>1</td>
<td>39</td>
</tr>
<tr>
<td><strong>Not dry</strong></td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td><strong>Outside</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dry</strong></td>
<td>2</td>
<td>36</td>
</tr>
<tr>
<td><strong>Not dry</strong></td>
<td>1</td>
<td>17</td>
</tr>
</tbody>
</table>
Now, if the numbers in Table 8 were taken at face value, it seems like the relative risk of experiencing a near crash relevant for driver with ACC/FCW is reduced with over 40%, compared to not having that ADAS in the vehicle.

The next question is how to apply this number to the target crash population, i.e. the full set of relevant crashes with their associated injuries/fatalities. The simplest approach would be to apply that number across the board, i.e. to the full target crash population with no further discrimination. When applied this way to the annual average of 2685 FCW relevant crashes in Sweden each year (see Table 7 above), that would mean a reduction of over 1100 crashes annually (600 ~in urban areas and 500 in rural).

However, one could also say that because all 12 of the “true” near crash events occurred on roads with a posted speed of 50 or 70 km/h, the prediction should be limited to those conditions. In that case, the target crash population is limited to 1861 crashes of which ~750 might be, representing ~28% of the total 2685 crashes that belong to the target crash population. Furthermore, if we were to take into consideration the above reasoning on how injury severity may be reflected in posted speed limits (see section 4.3), then an estimate for injury/fatality reductions when calculated in a similar fashion probably needs to be even more conservative, as the events which remain after filtering occur in the lower speed categories, where the relative risk of injury (given that a crash occurs) is lower.

As should be clear, the issue of for which crash typical conditions an event reduction is applicable has a huge impact on the benefit analysis, as does the number of events detected when that sample is small. In this example, the impact estimate spans the range from 28% to 40% depending on whether we go for the most optimistic or a more conservative estimate in terms of traffic conditions.

The number of events detected also has a huge impact when that sample is small. If the number of events in baseline and treatment changes only slightly (say one less in baseline and one more in treatment), the odds ratio and relative risk changes to 0.828 and 0.829 respectively, which means that the potential for crash reduction suddenly is slightly less than 20% (compared to the 40% above). This means that it is very important to make an estimate of how many events would be required to tell baseline and treatment apart with statistical significance before setting up the filtering process, in order to keep sufficiently many events to make the analysis reliable. Of course, that could come at the price of less rigorous (more inclusive) event selection process, so a working balance between sufficiently relevant and sufficiently many events has to be established.

When not enough events are found for a certain crash typical condition (but there are crashes in the database for this condition) a conservative estimate is to ignore that cell of the table, i.e. to limit prediction to cells for which there are enough data to make this prediction.

Note that because the actual function warnings were used to select events in this example, the issue of function availability is to some extent addressed (the function cannot warn when

### Table 8: Contingency table for events in baseline and treatment

<table>
<thead>
<tr>
<th></th>
<th>Baseline (function “off”)</th>
<th>Treatment (function “on”)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of crashes</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Km’s driven (duration)</td>
<td>4549</td>
<td>3920</td>
</tr>
<tr>
<td>Crash (or events) rate</td>
<td>0.00176</td>
<td>0.00102</td>
</tr>
<tr>
<td>Odds ratio</td>
<td>0.579</td>
<td>0.580</td>
</tr>
<tr>
<td>Relative Risk (RR)</td>
<td></td>
<td>0.580</td>
</tr>
</tbody>
</table>
it is not available). However, if some other criteria are used for event selection, such as a range/range rate criterion, the control for exposure must include not only the distance travelled in the treatment condition, but also the portion of that distance for which the function was actually available and working. As the latter hardly ever reaches 100%, and because the dependencies within the function on road conditions, lighting conditions, etc. is quite complex, finding out a correct number to work with is an interesting task on its own. This is some sort of a relevance filter, i.e. if LDW is available 80% of the time spent driving on highways, it can in principle not help in the last 20%; the target crash population is automatically reduced by 20% due to limitations in availability.

In terms of an EU 27 impact, a similar assumed percentage of reduction would have to be applied to the crash type Rear-End crashes in the eIMPACT safety spread sheet, and numbers calculated accordingly. Of course, as the number above comes from a limited dataset which has not been checked for consistency and biases, it only serves as an example and not as any type of prediction.

4.5 ABA examples

An ABA analysis can be performed in different ways, but the common denominator is that data for one or more variables are aggregated over a baseline and a treatment time segment, and then compared in order to identify changes. The general idea is to capture some overall change in driver behaviour that can be attributed to the presence of the ADAS, such a general reduction in speed or a general increase in time headway. Also, for many of the ADAS it is interesting to understand whether drivers increase or decrease their use of the ADAS over time, as that gives important information on whether the driver will have the ADAS switched on and will be willing to rely on its input when loss of control at some point is imminent. The procedure to go through when doing this has already been described in chapter 3.

4.6 PRM – estimating the influence of ACC on rear-end crashes

Event based approaches base their estimates on the number and severity of accident related events, and are therefore most applicable to ADAS acting on discrete events. For ADAS that work in a time-continuous mode these methods are less applicable because their operation induces a time-continuous change in the state of the vehicle (and possibly in the behaviour of the driver). While many aspects of these ADAS can be explored by averaging over one or more safety indicators as described in the ABA examples (e.g. mean speed or headway), for some of the ADAS such an averaging approach does not fully capture the intended effects of the function. This in particular relates to ACC and SRS. For ACC, the intent in terms of safety is to improve the precision in the distance keeping to a lead vehicle, which if successful would create an average increase in the time and space available if the lead vehicle should start to brake unexpectedly. In other words, though ACC’s vehicle regulation is time-continuous, the intended effect is to provide more margins in cases of emergency lead vehicle braking. Clearly, to assess this, just averaging over for example time headway fails to capture the dynamics of such situations. Instead, some approach that captures continuous effects of ACC in those situations has to be developed.

For these reasons this methodology introduces a simulation based method called physical risk modelling (PRM). The idea of PRM is to derive distributions of typical kinematic characteristics of lead vehicle following situations from FOT data when ACC is on and when ACC is off. Then one uses these distributions to explore a very large range set of possible situation outcomes in lead vehicle following situations, by doing Monte Carlo based simulation where the initial situation conditions are sampled from those FOT distributions. In this way one can explore how various combinations of initial conditions play out in terms of change in fatality and injury risk.
For a simulation approach like PRM, the way of describing the target crash population in the EBA example is no entirely suitable. Instead, a so called 'risk matrix' will be used. The risk matrix can be viewed as a variation of the target crash population cross tabulation above in the EBA example. However, rather than showing an accident frequency number per table cell, it indicates the relative risk of crashing and/or sustaining some form of injury under the particular conditions which identifies the cell, normalized over some exposure data. An overall change in risk due to the ADAS is determined by assigning the FOT data distributions to these cell conditions in the 'risk matrix', and then simulating how the potential conflict outcomes given the initial conditions of each cell changes when those conditions change (as a function of ADAS presence).

In short then, PRM estimates the number of accidents as the product of accident probability, accident severity and exposure, following established practice. The first two factors together are called accident risk. In EuroFOT this method will be applied to the functions ACC and SRS. Additional requirements for this implementation is that it should be usable without video data, because most of the EuroFOT vehicles do not have video data, that it should be usable without in-depth accident statistics, because at the EU level there is only a high level accident database, and that it should run (almost) automatic after initial preparation. The latter requirement is motivated by the huge amount of data being produced in EuroFOT which makes an interactive form of analysis practically impossible. Another motivation is that due to the size of project, the experts working with the data are typically not the safety experts involved in modelling safety impacts. The assessment method is set up such that users of the method merely need to provide the kilometres driven under various circumstances, from which the safety impact is determined automatically.

The approach will be elaborated for and applied to rear end collisions only. In principle the approach is applicable to other collision types as well. It does however need two elements, which are currently not available for other crash types. The first element is that the relevant factors that determine the crash risk need to be measured in the FOT. E.g. the position of vulnerable road users is not measured in the FOT. The second element is that the empirical relation between impact speed and fatality/injury risk needs to be known from historical crash statistics. These data are not available for e.g. side-by-side collisions. When both elements are available, a physical risk indicator (e.g. impact speed / run of the road speed) can be calculated and translated into the injury and fatality risk.

4.6.1 How does it work?

As stated above, this approach is designed to assess time continuous ADAS. Therefore the full range of car-following situations is divided into a grid, or matrix. A risk is then calculated for each cell of the matrix using the physical risk model. Both the risk matrix and the physical risk model are described.

The risk matrix

This approach identifies the variables that impact risk. The variables that determine the risk of rear-end crashes and the injuries and fatalities are:

- $V_{\text{lead}}$, speed of leading vehicle
- $V_{\text{follow}}$, speed of following vehicle
- $A_{\text{lead}}$, acceleration of leading vehicle
- $A_{\text{follow}}$, acceleration of following vehicle
- PRT, perception reaction time
- THW, time headway
For each variable, the feasible data range is divided into several intervals. Combining the intervals for all variables defines a “grid” in the feasible data set; see Figure 10 for a two-dimensional example. For each “box” in the grid, it is determined how much the risk is changed compared to the average risk if the state of the vehicle and the driver is in that box, leading to a (hyper-) matrix of risks. For example, in the hypothetical case of Figure 10:

- If the speed is between 60 and 90 and the Time headway is bigger then 1.5, then the risk decreases by 5% compared to the average risk.
- If the speed is between 90 and 120 km/h and the Time headway is smaller then 0.5, then the risk increases by 17% compared to the average risk.

Figure 10: Hypothetical example of a risk matrix in two dimensions.

Each box contains a relative risk (some shown as illustration).

**Calculating the risks**

The risks in the matrix are calculated by physical risk model based on starting conditions of the input variables. This model performs a risk assessment by developing a physical model for the probability of a collision and the severity of the impact. The approach is outlined in Figure 11.

Figure 11: Physical risk model. Left: pre-collision. Right: post-collision.
Two vehicles are considered: a leader and a follower. The probability that the follower will collide with the leader and the severity of that collision are determined as follows:

The calculation of impact speed given starting conditions is based on the Safe Headway Distance. The SHD is a size for incident probability, which is based on the concept that the minimum stopping distance of the lead vehicle should be larger than the minimum stopping distance of the following vehicle plus the distance headway:

\[
SHD_i = \max \left( \text{Diff}_i, 0 \right)
\]

\[
\text{Diff}_i = (V_{\text{Leading}} \times h - V_{\text{Following}} \times \text{PRT}) + \left( \frac{V_{\text{Leading}}^2 - V_{\text{Following}}^2}{\text{acc}_{\text{Leading}} - \text{acc}_{\text{Following}}} \right)
\]

- \(V_{\text{lead}}\), speed of leading vehicle (m/s)
- \(V_{\text{follow}}\), speed of following vehicle (m/s)
- \(A_{\text{lead}}\), acceleration of leading vehicle (m/s²)
- \(A_{\text{follow}}\) acceleration of following vehicle (m/s²)
- PRT, perception reaction time (sec)
- \(h\), time headway (sec)

If the following condition is met, a traffic conflict in which a lead vehicle suddenly breaks does not result in an incident.

\[
\left( V_{\text{Leading}} \times h - \frac{V_{\text{Leading}}^2}{\text{acc}_{\text{Leading}}} \right) > \left( V_{\text{Following}} \times \text{PRT} - \frac{V_{\text{Following}}^2}{\text{acc}_{\text{Following}}} \right)
\]

Under the assumption that the leader keeps decelerating at the selected level until standstill, the probability of a crash and the impact speed can be calculated.

The physical risk model provides a way to compute the risk for a given value of the risk parameters speed and perception-reaction-time as the expected value of the number of fatalities per kilometre. The (uncalibrated) risks can be computed without making use of the FOT data.

The physical risk model determines the risk by Monte Carlo simulation, in the following way:

1. For each cell in the risk matrix, choose at random a large number (e.g. 1000) of parameter points in the cell. A parameter point defines the values of all the risk parameters. It also defines values for external parameters that are drawn from some probability distribution (for example, in the discussion on the physical risk model for rear-end collisions; this includes the deceleration of the predecessor.) This starting point, therefore, is chosen at random, independent from the FOT data.
2. For each parameter point, use the physical risk model to compute the expected number of fatalities per kilometre.
3. For each cell, average the outcome of step 2 over all parameter points in that cell. This gives the risk \(r(s, t)\) for the cell.

Note that not all six parameters are measured in the FOT. The perception reaction time and the acceleration of the predecessor are not. Since it does obviously influence the injury and fatality risk, the variable is included in the physical risk model to calculate the risks of the cells. However, when assigning the FOT data to the risk matrix, the acceleration of the predecessor is assumed to be similar the acceleration of the follower, corrected for the reaction time, and the value for PRT was drawn from a distribution.
The distribution of the PRT cannot be obtained from the FOT data, since it is not measured. It is therefore based on the results of a literature review performed by (Farber et al., 2010).

This review concludes with that “in an emergency situation in which the hazard is relatively conspicuous and first appears directly ahead or nearly so available research suggests that most drivers will respond in about 1.5 to 2.0 seconds. The minimum time to respond is unlikely to be much less than 0.75 second. These are simple or straightforward situations. Many situations are complex and must be dealt with as such.”

It is also stated there that the PRT data typically lies on a skewed distribution.

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentile of Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td>1. Perception</td>
<td></td>
</tr>
<tr>
<td>a. Latency</td>
<td>0.24</td>
</tr>
<tr>
<td>b. Eye Movement</td>
<td>0.09</td>
</tr>
<tr>
<td>c. Fixation</td>
<td>0.20</td>
</tr>
<tr>
<td>d. Recognition</td>
<td>0.40</td>
</tr>
<tr>
<td>2. Decision</td>
<td>0.50</td>
</tr>
<tr>
<td>3. Brake Reaction</td>
<td>0.85</td>
</tr>
<tr>
<td>Total A (1a-d+2+3)</td>
<td>2.3</td>
</tr>
<tr>
<td>Total B (1c-d+2+3)</td>
<td>2.0</td>
</tr>
<tr>
<td>Total C (1a-d+3)</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Table 9: Results of an effort to deduce driver PRT, based on summation of assumed components taken from the research literature by McGee et al. [7]

It also presents Table 9, produced by McGee et al. [7], who arrived at PRT estimates by listing the individual components, surveying the literature to find appropriate values for each, and summing these values to obtain totals. Farber et al. [47] states that “There are two questionable assumptions one must make in using these data. The first is that there is no overlap in the execution of these steps, so that the times can be summed. The second assumption is that an individual will perform at the same percentile level in each step. For example, an individual with latency at the 75th percentile is assumed to perform at the 75th percentile for each of the remaining five steps. Results of studies that have made some effort to separate the steps in perception response (e.g., Olson et al. [46]) suggest that this is not the case. If not, this assumption would result in reasonably accurate estimates of PRT at the median, but progressively greater overestimates at higher percentiles.”

For a lack of better estimates of the Perception Reaction Time, these numbers are used to estimate a distribution despite the risk of overstatement due to the assumptions mentioned above and questions of applicability of these data to the specific rear-end crash scenario. The effect of the possible overestimation on the calculated safety effect will be tested in a sensitivity analysis.

The distribution uses the data from ‘total B’ which is assumed to best represent people’s reaction in car-following scenarios where the lead vehicle suddenly brakes. It consists of
fixation, a decision to brake, take evasive action or a combination of both, and the brake reaction itself. It also uses the conclusion that the minimum respond time is 0.75 sec.

![Brake Reaction Time distribution](image)

Figure 12: Estimated distribution of BRT based on total B from Table 9

**Acceleration of the predecessor**

The acceleration of the predecessor is not measured in the FOT.

### 4.6.2 Discussion, assumptions and limitations

As in all approaches for safety impact assessment there are many dependencies, and many of them are unknown. This requires strong assumptions.

**Assumptions**

- Car-following conditions are a measure for rear-end fatality and injury risk.
- The ITS function does not influence the relation between car-following conditions and risk.
- Physical risk model assumptions
  - Leader decelerates constantly at \( AL \) m/s\(^2\) from speed \( VL \) m/s
  - Follower is \( THW \) s behind, maintains speed \( VF \) m/s for \( PRT \) s, then decelerates constantly at \( AF \) m/s\(^2\)
  - \( AL = AF \), due to correlation
  - \( PRT \) independent, distribution based [7]
  - Fatality/injury probability for impact speed from [54]
Calibration of risks

As mentioned before, the risk for unequipped drivers should equal the default risk. This places a condition on the choice of the risks. This condition is not expected to be fulfilled automatically with either of the above methods. However, it can be fulfilled by calibrating the risks, as follows:

Let \( c(i, j, k) = \frac{R_{\text{def}}(i, j, k)}{R(u, i, j, k)} \) be the ratio of the default risk and the risk for unequipped drivers, calculated using the non-calibrated risks \( r(s, t) \). Define the calibrated risks \( r_c(s, t) \) by \( r_c(s, t) = c(i, j, k) r(s, t) \). Then the risk for the unequipped drivers, computed using the calibrated risk factors, equals the default risk. Indeed,

\[
R_{\text{calibrated}}(u, i, j, k) = \left( \frac{\sum_{s,t} r_c(s, t) n(f, s, t)}{\sum_{s,t} n(f, s, t)} \right) \times R_{\text{def}}(i, j, k) = c(i, j, k) R(u, i, j, k) = R_{\text{def}}(i, j, k).
\]

Thus, the calibrated risks correctly represent the risk for the unequipped drivers, and therefore they should be used to compute the effectiveness factors and assess the safety impact.

Table 10: Average probability rear-end fatalities and injuries for EU25 (based on eIMPACT)

<table>
<thead>
<tr>
<th></th>
<th>Fatalities</th>
<th>Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>total number (2010)*</td>
<td>36069</td>
<td>1488975</td>
</tr>
<tr>
<td>% rear-end (2005)*</td>
<td>5%</td>
<td>12%</td>
</tr>
<tr>
<td>km driven (2010)**</td>
<td>3.6E+12</td>
<td>3.6E+12</td>
</tr>
<tr>
<td>number of rear-end accidents</td>
<td>1803</td>
<td>185886</td>
</tr>
<tr>
<td>probability per km</td>
<td>5.0E-10</td>
<td>5.1E-08</td>
</tr>
</tbody>
</table>

*eIMPACT D3 [23], p.50 (based on ProgTrans European Transport Report 2004)

**eIMPACT D4 [22], p.36

Other crash types

The approach is in principle applicable to other crash types than rear-end crashes as well. In practice either the factors that influence crash risk are not measured in the FOT (e.g. the presence of pedestrians of opposing vehicles) or the empirical relation between impact speed and risk is not known (side by side accident). For these reasons, the approach is so far limited to rear-end crashes.

4.6.3 Using the physical risk matrix approach

The approach will be applied by the VMCs to determine the safety impact of an ITS function in terms of the reduction of fatalities, severe and slight injuries due to rear-end crashes.

Before this safety impact can be used in the cost benefit analysis it will be scaled up using the eIMPACT approach. The impact is determined by comparing the risk per kilometre of vehicles driving without the function (baseline) and with the function (treatment). The risk per kilometre is obtained by assigning the FOT data to the cells of the cells of the matrix. Each data-point contains the parameters.
which match the dimensions of the matrix. The data should be assigned to the cells according to the values of the parameters (feeding the data points to a Matlab script). The total accident risk can be determined by computing the overall risk as the weighted sum of the risks, where the weights are the fraction of FOT data that lies in that cell.

This has to done for baseline and treatment. The impact of the function is the ratio of baseline and treatment. This ratio can be determined for part of the FOT data representing the situational variables to isolate the effect of these situational variables, for instance to differentiate between the effect on motorways, rural road and urban roads.

The data can be assigned by running a Matlab script that requires the four parameters as input for each data point and calculates the risk. For the VMCs this means they have to perform the following steps

*Step 1: Determine which part of the FOT data is baseline and which is treatment*

*Step 2: Assign the baseline FOT data points to the risk matrix (Matlab script)*

*Step 3: Assign the treatment FOT data points to the risk matrix*

*Step 4: Determine the ration between baseline and treatment*

For each situational variable determine which part of the FOT data is one situation (e.g. rain and dry). Repeat these steps for all situational variables and compare the ratios between baseline and treatment for the different conditions.

### 4.6.4 Current status

Some first tests have been done with a small data sample. Though the results do not have sufficient statistical power for drawing conclusions (due to the small data set), the results seem to be reasonably in line with expectations. Additional testing is being performed with a larger data set, including sensitivity analysis and validation with crash statistics. The first results do show that the risk matrix approach functions and is applicable to rear-end crashes. Additional sensitivity tests will be done based on a larger data set.

The relation between impact speed and fatality and injury risk used for the initial testing are based on US crash statistics of over 20 years old as described in [54]. An updated relation between impact speed and risk will be determined based on more recent data from a German crash database.

### 4.7 Methodological concerns

In relation to the different ways of estimating a safety impact for the euroFOT functions described above, there are a number of methodological concerns that can be raised. Some of the most important ones are discussed in turn below.

#### 4.7.1 Predictors of crash involvement and their relationship to safety impact assessment

The relationship between changes in the evaluated crash predictors, when comparing baseline and treatment, and accident involvement is not straightforward. This is a problem for all three approaches (ABA, EBA and PRM) described above. Ideally, one would select and
compare only events and/or aggregate measures which are known to be predictive of actual crash involvement, i.e. where it is legitimate to infer that a particular change in what is measured corresponds to a particular change in crash frequency. If this relationship is established, an experimentally identified reduction in the treatment phase could then be used to directly predict a reduction in future crash involvement.

Unfortunately, such relationships are yet not fully established, at least not for FOT type data. For example, in terms of events, while hard braking may seem a plausible candidate for event selection, in the VTTI 100 car study [13] they were not able to reliably identify near-crash events in lead vehicle following situations based on hard braking alone, i.e. such braking occurred also in many driving situations which they did not think were indicative of crash risk. Similarly but in terms of aggregate measures, while a reduction in mean speed could be indicative of a reduction in crash involvement, there is no empirical base available for estimating the importance of mean vehicle speed in FOT data in relation to crash involvement. The currently most well developed basis is the power model by [33] where a relation between some speed parameter (usually mean speed) and accident severity is inferred. However, there are some methodological concerns which make it difficult to apply this model straight off on FOT data. Most validation studies have focused on speed choice on highways and rural roads in free flow conditions, and the empirical basis comes from cross-sectional data measured on selected road sections rather than from mean speeds as chosen by an individual driver across all possible driving conditions. The applicability of the model on FOT data therefore yet has to be validated (for an excellent discussion, see [2]).

It follows that insight into crash causation mechanisms is the key both to the selection of relevant measures of change between baseline and treatment, as well as for interpretation of what those changes mean, in terms of how the target crash population may change if the evaluated ADAS is introduced on a larger scale in the vehicle fleet. Thus care has to be applied in choosing which indicators to build the final impact assessment on. For the expansion to EU27, it probably makes sense to use indicators which seem to behave consistently across populations, i.e. where the impact on driver behaviour is similar and comparatively of the same magnitude across for example Germany, Sweden and Great Britain. It also follows that supporting the indicators with empirical evidence of how they represent underlying accident causation mechanisms is highly desirable, and something which should accompany the impact analysis.

In terms of the latter, several types of providing such empirical support may be possible. One would be to couple the analysis of changes between baseline and treatment with findings from crash causation investigation projects such as SAFETYNET [16]. If the event and/or aggregate measure selection criteria explicitly reflect previously identified accident causation mechanisms, the case for arguing their relevance is certainly strengthened.

4.7.2 How to integrate results from different indicators in step two of the safety impact analysis process

In euroFOT, a number of elaborated ways of predicting changes in safety related metrics are being tested (by means of ABA, EBA or PRM analysis as described above). While the adopted predictors on their own may have a proven direct link with crash causation, together they can help understanding the major differences between baseline and treatment and provide a possible impact range to use when going to step three of the procedure (interpreting what the change would mean if the function(s) were widely deployed in Europe). The methodology outcome could be described as illustrated in Figure 13. For each function evaluated, the effect on the driving population of the study is assessed from a number of results coming from answers to the safety-relevant hypotheses being explored.

Note that different results from different VMCs can be combined in Figure 13 by, for example, modifying the error bars. The same plot can be made for, for example, different road types or speed bins, if a more fine-grained analysis is required. In the best of worlds, all safety
indicators would point in the same direction for a particular function, whether it is a general increase of decrease in perceived safety in treatment. However, most likely there will be some contrasting or conflicting findings, as well as statistically significant and not significant results.

Figure 13: Hypothetical changes between baseline and treatment in terms of event frequencies and aggregated driver performance measures

The indicators in Figure 13 above are a relatively straight forward result from FOT data analysis. Indicators in Figure 13 are not likely to be orthogonal (e.g. high accelerations are less frequent at lower speed). However, they can most likely be viewed as representations of the same phenomena from complementary angles.

Given this way of viewing them, the indicators in Figure 14 may be integrated to explain the mechanisms behind the phenomena. For example, let's hypothesize we find the initially somewhat counterintuitive results illustrated in Figure 14, i.e. with ACC on, there is an increase in headway, a decrease in severe near crashes, and faster driver responses, but also an increase in mean speed and the number of harsh brakings.
Figure 14: Hypothetical changes between baseline and treatment in terms of event frequencies and aggregated driver performance measures in a specific example.

By integrating the results in Figure 14, the results of step 2 in the safety-impact analysis (i.e. identifying change between baseline and treatment) could be presented in something approaching the following format. First, ACC significantly impacts safety as illustrated by the significant decrease in severe near-crashes. That means while increased mean speed previously has been found to increase accidents [10], ACC seems to neutralize the underlying accident causation mechanism behind those results. One way of explaining this would be through the significantly larger headway distance found in the ACC on condition, which in practice provides the driver with more time to react in any given safety-critical situation. The significant decrease in reaction time may also be contributing, by enabling an earlier start of the speed reduction, and thus providing a larger safety margin, when encountering safety-critical situations. Finally, the significant increase in harsh braking frequency may be an effect of the ACC braking-capacity warning, which also may be the underlying reason for the decreased reaction times.

4.7.3 Unintended effects – what if a function influences other crash types than the intended one(s)?

An often voiced worry concerns unintended side effects, i.e. that the presence of one function will lead to increases in crash types which are not directly related to the function. A hypothetical example would be FCW presence leading the driver to trust the FCW to handle forward events, in which case lateral control may decrease as a side effect of reduced driver attention to the primary driving task. If this occurs, FCW presence may lead to an unintended
increase in the number of inadvertent lane departures, which in turn might lead to an increase in road departure crashes.

This conundrum actually only can be addressed on an empirical basis. Basically, for something like this to happen, some form of mediating mechanism must exist (such as the decrease in lateral control in the example above). If such a mechanism exists, its nature and influence can be hypothesized on and tested for. For the above example, this would consist of looking at the frequency of lane excursions in FCW on and FCW off conditions (and most likely with LDW on/off as a control factor).

However, as far as the authors are aware, while there is a substantial amount of research on behavioural adaptation, conclusive evidence of how such adaptation significantly increases unintended crash involvement has yet to be presented. This is what can be expected, given that this is a research topic for which only recently the relevant amounts of data are becoming available empirically investigation. In other words, while unintended side effects certainly are a possibility, there is still a lot of work to do in describing and validating mediating mechanisms (i.e. not only in the sense that behaviour changes, but that crash risk changes as well). For euroFOT, this is probably best viewed as a very interesting future data analysis topic that should be explored, either within the project if resources allow or as a later follow up analysis project.
5 Traffic efficiency impacts

5.1 Introduction

In chapters 1 and 2 of this document the introduction to the assessments and the general set-up of the assessment methodology are described. In this chapter the methodology for assessing traffic efficiency is described in detail. The traffic efficiency evaluation will be carried out for all functions and test sites, by the corresponding Vehicle Management Centres (VMCs). Key questions in the methodology (as stated in a general way in the introductory chapter) are:

- What data are needed for carrying out the traffic efficiency impact assessment?
- What steps need to be taken in the traffic efficiency impact assessment, or: how to calculate the traffic efficiency impacts?
- What are the outputs the traffic efficiency impact assessment needs to deliver?

This introductory section describes an overview of the traffic efficiency impact assessment including inputs and outputs (5.1.1), required performance indicators, research questions and hypotheses (5.1.2), a brief work process for the traffic efficiency impact assessment including steps, roles of partners and timeline (5.1.3) and outline of the rest of this chapter (5.1.4).

5.1.1 Overview traffic efficiency impact assessment

Besides being able to analyse the function under research by testing hypotheses and answering research questions, the traffic efficiency impact assessment needs to provide input for the cost-benefit analysis (CBA). The CBA in euroFOT requires information about the costs and benefits of the functions at the EU level. The traffic efficiency benefits (some possibly negative) are derived from the traffic efficiency impact assessment. The following quantified traffic efficiency impacts have to be provided to the CBA (at the EU level):

- **Travel time changes** (direct effect)
- **Changes in the amount of accident related congestion**, based on changes in number of accidents (indirect effects)
- **Homogenisation / reduction of congestion effects** for environmental impact assessment (direct effects)

Inputs for the traffic efficiency impact assessment are the FOT results coming from the data analysis. Performance indicators that are needed are specified in the next section, situational variables are already given in chapter 2.

This chapter describes how to go from calculated performance indicators to tested hypotheses, answered research questions and quantified traffic efficiency impacts. This includes translating small scale results to the EU level and considering different scenarios.

In Figure 15 a high level overview of the steps before, in, and after the traffic efficiency impact assessment is given. A certain function is tested in a FOT and produces FOT results (performance indicators, situational variables). Then the traffic efficiency impact assessment starts: direct effects and indirect effects are calculated. Direct effects can be calculated by a linear and by a modelling approach. Indirect effects are calculated via the safety impact assessment results: number of avoided fatalities and injuries. Direct and indirect effects together form the total traffic efficiency impact. Results of the traffic efficiency impact assessment provide input for the cost-benefit analysis. Here the traffic efficiency impact assessment ends. At several points in the overview figure, external data may serve as additional input. This is not displayed in the figure.
Figure 15: Overview traffic efficiency impact assessment

The three red boxes in Figure 15 are worked out later in this chapter. More extensive figures are then given with the steps that need to be taken.

**Overview traffic efficiency impact assessment per function**

Table 11 presents how the different functions need to be assessed (descriptions of the functions tested in euroFOT can be found in [20]). For each function it shows what types of effects (direct and/or indirect) can be expected and need to be assessed. It also shows which assessment approach (linear or modelling) is the most applicable one. Check marks indicate the impacts that are relevant and therefore need to be assessed. Check marks between brackets indicate that this impact may need to be assessed if the FOT data show an effect of the function on regular driving behaviour. For all functions, an assessment by the linear approach is possible to find non-interaction effects. This is not specifically indicated in the table unless no interaction effects are expected.
Table 11: Functions and types of traffic efficiency assessment

<table>
<thead>
<tr>
<th>Function</th>
<th>Indirect effects on efficiency</th>
<th>Direct effects on efficiency</th>
<th>Linear approach</th>
<th>Modelling approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>FCW</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>CSW(^3)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SL/CC</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>LDW</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>BLIS</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SafeHMI</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Not possible, because only change in lateral behaviour expected, which cannot be modelled</td>
</tr>
<tr>
<td>FEA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Not possible, because only change in lateral behaviour expected, which cannot be modelled</td>
</tr>
<tr>
<td>IW</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>(not possible, because limited number of equipped test vehicles)</td>
</tr>
</tbody>
</table>

5.1.2 Research questions, hypotheses and performance indicators

Earlier in the project research questions and hypotheses for the evaluation are formulated. The following research questions are relevant for the traffic efficiency impact assessment:

What is the impact of a certain function on:

1. Average network or journey speed
2. Amount of delay
3. Variation in travel times
4. Network performance (vehicle km travelled) per road category: exposure
5. Section performance (vehicles per h)

In Table 12 below, the hypotheses relevant for efficiency are specified. For each hypothesis, it is indicated for which function groups the hypothesis is relevant, and it is indicated whether it can be tested by the linear approach or the modelling approach. The function groups contain the following functions:

- Longitudinal
  - ACC
  - FCW
  - SL/CC
- Lateral
  - LDW
  - BLIS

\(^{3}\) We do not expect to measure any effects, taking into account the limited number of instrumented vehicles in the set-up of the pilot with CSW

\(^{4}\) There are no loggings of the suggested route and the compliance of the driver
Table 12: Global assessment efficiency hypotheses, relevance for the four function groups and choice in approach (linear or modelling)

<table>
<thead>
<tr>
<th>No.</th>
<th>Hypothesis</th>
<th>Function group</th>
<th>Linear approach</th>
<th>Modelling approach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Longitudinal</td>
<td>Lateral</td>
<td>SafeHMI</td>
</tr>
<tr>
<td>1</td>
<td>The average speed will decrease</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>The number of trips made will increase</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>3a</td>
<td>The number of vehicle km travelled will increase (tested with subjective data)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>3b</td>
<td>The number of vehicle km travelled will increase (to be tested per road category, with objective data)</td>
<td>✓ (✓)</td>
<td>✓ (✓)</td>
<td>✓ (✓)</td>
</tr>
<tr>
<td>4</td>
<td>The amount of recurrent delay (e.g. daily congestion in peak hours) in the network will decrease</td>
<td>✓ (ACC and SL/CC)</td>
<td>✓ (Safe-HMI)</td>
<td>✓ (ACC and SL/CC)</td>
</tr>
<tr>
<td>5</td>
<td>The amount of incidental (accident-related) delay in the network will decrease</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>The travel times will decrease</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

In the rest of this chapter, it is indicated at which moment and during which analysis the research questions and hypotheses can be tested or answered.
For the calculation of direct and indirect effects and for both approaches, certain data are needed: **performance indicators** and situational variables. The situational variables are the same for the linear approach and the modelling approach and are already given in section 2.3. More performance indicators are needed in the modelling approach than in the linear approach. The complete list of performance indicators for the modelling approach is given in section 5.3. For both approach it is assumed that from data analysis the following performance indicators have been obtained:

- Speed (km/h) (average for the linear approach and distribution for the modelling approach, see section 5.3). For the linear approach over all vehicles and all trips.
- The average number of km driven per day for each vehicle

Furthermore, for the indirect effects the results from the safety impact assessment are needed: the change in number of fatalities and injuries, split for some situational variables. See section 5.4 for more explanation on this.

### 5.1.3 Work process

Data analysis is performed by the VMCs before the traffic efficiency impact assessment starts. TNO provides the methodology for the traffic efficiency impact assessment and supervises the analysis. The VMCs do the actual implementation and analysis: testing of hypotheses and carrying out of the traffic efficiency impact assessment, using the methodology described in this document.

As stated earlier in this chapter, the modelling approach for calculating direct traffic efficiency effects makes use of simulation tools. These simulation tools are available at IKA and TNO (both German1), but not at the VMCs themselves. IKA and TNO will carry out simulations for some functions (see Table 11) for the VMCs. It is defined in this chapter which information is needed from the other VMCs in order to conduct the traffic efficiency impact assessment.

The functions that are indicated for the modelling approach are ACC, SL/CC and FEA. SafeHMI was originally selected for the modelling approach, but this will not be possible because of limited data loggings. In an overview of the functions for the modelling approach is given, including the corresponding VMCs and responsible simulation partner.

Table 13: Overview of functions for traffic efficiency modelling and the corresponding partners responsible for the modelling

<table>
<thead>
<tr>
<th>Function</th>
<th>VMC</th>
<th>Cars or trucks</th>
<th>Simulation by IKA or TNO</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC</td>
<td>German 1, Sweden</td>
<td>Cars</td>
<td>IKA</td>
</tr>
<tr>
<td>ACC</td>
<td>German 1, Sweden</td>
<td>Trucks</td>
<td>IKA</td>
</tr>
<tr>
<td>SafeHMI</td>
<td>German 2</td>
<td>Cars</td>
<td>TNO</td>
</tr>
<tr>
<td>SL/CC</td>
<td>France</td>
<td>Cars</td>
<td>TNO</td>
</tr>
<tr>
<td>FEA</td>
<td>Sweden</td>
<td>Trucks</td>
<td>IKA</td>
</tr>
</tbody>
</table>
5.1.4 Outline

In the next three sections the red boxes from Figure 15 are worked out: the methodology for the linear approach for calculating direct traffic efficiency effects is explained in section 5.2. The methodology for carrying out the modelling approach for calculating the direct traffic efficiency effects can be found in section 5.3. The methodology for calculation of the indirect traffic effects is described in section 5.4. In Annex 4 descriptions of the simulation models of TNO and IKA can be found, as well as a brief comparison between the models. Function descriptions can be found in [20].

5.2 Direct traffic efficiency effects – linear approach

Direct traffic effects (changes in travel times) can be calculated by the linear approach: FOT data are used directly and effects are scaled up to EU level via situational variables. This linear approach will be applied to all functions. For three functions (ACC, SL/CC and FEA) additionally the modelling approach is applied, since for these functions it is expected that equipped vehicles influence other road users and these functions can be modelled in micro-simulation models currently available and suitable for network analyses.

In Figure 16 the linear approach is illustrated.

Efficiency impacts assessment (linear approach)

Figure 16: Overview linear approach for calculating direct traffic efficiency effects
Objective FOT data, such as speeds and accelerations, are measurements from the CAN bus, video data, etc. Objective data can provide information on increase/decrease in exposure in a "within subject" setting (the same group of participants first driving without the function, and then with the function), therefore the dotted line. Subjective FOT data are data acquired through questionnaires, interviews, etc.

We assume that data are available as stated in the introduction (under ‘data needs’). Then the methodology for the linear approach for calculating direct traffic effects is as follows, in eight steps. In between it is indicated which hypothesis (see Table 12) and research questions (see subsection 5.1.2) can be tested at what moment. Two of the hypotheses (numbers 4 and 5) and some of the research questions are tested at other moments, when using the modelling approach and when calculating the indirect traffic effects.

1. Check for which situational variables EU data are available with regard to mileage (this step needs to be carried out once for all functions). For example, if there are no data on road curvature available, it does not make sense to split performance indicators for this situational variable. To give an example, for a certain situational variable with 3 levels the following data should be available at the EU level:
   o Kilometres driven at level 1
   o Kilometres driven at level 2
   o Kilometres driven at level 3

If no EU data are available for a certain situational variable, it depends on the relevancy checks of steps (2) and (4)/(5) what to do. If this situational variable is relevant (for speed or exposure) an assumption can maybe be made. If the situational variable is not relevant, it is not a problem. This step will be carried out by TNO, see at the end of this chapter for some more details.

The following steps need to be carried out for every function separately.

2. Calculate difference in speed between driving with function and driving without function from objective FOT data for (combinations of) situational variables.
   o Check which situational variables are relevant (i.e. the speed difference differs depending on the level of the situational variable when comparing driving with function to driving without function)
   o Ideally, for the relevant situational variables also all combinations are researched. However, this takes more effort and time and data sets are smaller (less chance of significant results). Therefore we will look at combinations of two situational variables at a maximum. This is only possible if there are European data available on these combinations, or if it is possible to make a reliable assumption.

   After step 2, hypothesis 1 (‘the average speed will decrease’) can be tested.

   After step 2, research question 1b (‘what is the impact of the function on journey speed’) can be answered.

3. From (2), calculate change in travel time per km for the relevant (combinations of) situational variables.

   After step 3, hypothesis 6 (‘the travel times will decrease’) can be tested.
Step 4 and 5 are about exposure. It is very difficult to verify whether a change in exposure can be assigned to the function, or if it is a coincidence or due to other factors, such as seasonal effects. Therefore, only if the subjective data indicate a clear change in exposure, this change in exposure is calculated from the objective data and used in the analysis. Also, it will be checked if it is likely that the change in exposure can be assigned to the use of the function.

4. Check in subjective FOT data (questionnaires) if there is a significant change in exposure. This can be a change in total number of kilometres driven. It is also possible that there is no change in total number of kilometres driven, but a shift in the circumstances under which these kilometres were driven: a change in exposure for situational variables. For example more kilometres driven on motorways instead of on rural roads.

5. If the answer to (4) is ‘yes’, calculate the change in exposure for (combinations of) situational variables (so restricted to those found in (4)).
   
   o Check which situational variables are relevant (i.e. for which situational variables there is a change in exposure when comparing scenario without function to scenario with function).

   o Ideally, for the relevant situational variables also all combinations are researched. However, this takes more effort and time and data sets are smaller (less chance of significant results). Therefore we will look at combinations of two situational variables at a maximum. This is only possible if there are European data available on these combinations, or if it is possible to make a reliable assumption.

6. Aggregate and (levels of) situational variables. Situational variables that are not relevant with respect to change in speed AND not relevant with respect to exposure, can be disregarded from now on (aggregated). This means that the data for these situational variables will be taken together.

   What is left as separate situational variables are the ones that are relevant with respect to change in speed AND/OR exposure.

7. From change in exposure (5), taking into account the processing in (6), a database of kilometres travelled in EU for (combinations of) situational variables, and a penetration rate, calculate the kilometres travelled in EU with and without the function, for (combinations of) situational variables. Of course this depends on the data found in (1).

8. From (3) and (7), calculate the total change (in %) in travel time. Again taking into account the processing in (6).

The scaling up step (7) is described in more detail further in this document, in chapter 7. The exposure effects of SafeHMI are described in more detail at the end of this section.

What is needed for the steps that can be done already before FOT data are available is the following:

After step 4, hypothesis 3a (‘the number of vehicle km travelled will increase’ – tested with subjective data) can be tested.

After step 5, hypothesis 3b (‘the number of vehicle km travelled will increase, to be tested per road category’ – tested with objective data) can be tested.

After step 5, research question 4 (‘what is the impact of the function on network performance (vehicle km travelled) per road category’) can be answered.
Check for EU data (statistics) on situational variables
Check what data are available in the database (when database set-up is ready). If not everything we need according to the steps above is available, an alternative needs to be searched.

The linear approach could lead to an excel sheet where performance indicators can be filled in (per situational variable or combinations) and effect is calculated. This will be decided on when carrying out the impact assessment.

Data collection on situational variables

The data on situational variables that will be collected at the EU level has a great influence on the impact assessment. Data will be collected through European and possibly national databases, making use of the work done in other European projects such as eIMPACT. We expect to find (at least for some countries) data on:

- Road classification (road types)
- Weather – from meteorological institutes, using averaged data on for example rain hours
- Traffic situation (congestion / free flow)
- Lighting – using data on time of sunrise and sunset

We expect that it will be difficult to find data on number of lanes, road curvature, intersections and load of trucks.

Most important are data on road classification: how many kilometres are driven on motorways, rural roads and urban roads.

If necessary, assumptions will be made on situational variables.

Exposure effects SafeHMI

In the part of euroFOT called SafeHMI, navigation functions with different levels of integration are tested. Navigation functions, other than the other functions, intend to have an exposure effect; they intend to change strategic driver behaviour, unlike the other functions that intend to change tactical driver behaviour. With navigation functions shorter routes with fewer detours are taken. The exposure effects are therefore explicitly addressed. For testing of the efficiency related hypotheses we plan to do the following, after having analysed two pilot tests:

- Due to limited loggings it is not possible to reconstruct the route advices of the navigation functions used in the FOT. What we will try to do is find a reference navigation function, probably in the form of an internet route planner, which provides us with reference routes: the length in km and duration will be estimated for each route.
- Then, the actual number of km driven will be subtracted from the estimated km for each route. For values larger than zero the actual route was longer than the estimated route and for values smaller than zero the actual route was shorter than the estimated route. The same will be done for travel time: the differences between the...
travel times estimated by a route planner and the actual travel time will be calculated. The parameters for each route can then be averaged for all unfamiliar routes\(^5\). Thus we can compare whether the relative number of km driven increases or decreases (in relation to the estimated km) with and without navigation function.

- Furthermore, it can be tested whether the absolute number of kilometres travelled and the absolute travel time differ between driving with and without navigation system for unfamiliar routes. This can be done separately per road category.

| After this step, hypothesis 3 (‘the number of vehicle km travelled will increase’) can be tested. |
| After this step, research question 4 (‘what is the impact of the function on network performance (vehicle km travelled) per road category’) can be answered. |

- An algorithm is available to analyse the percentage of time spent in congestion. This algorithm is currently only defined for highways. Since this parameter evaluates the dynamic routing function and not the route guiding function of the navigation function, it can be analysed both for familiar and unfamiliar routes.

One of the problems at the moment is to find (internet) route planner software that can provide the needed route information in an automatic way. So, depending on the amount of data and trips it might become necessary to restrict the analysis to a subset of trips (e.g. certain number of unfamiliar trips per driver and condition) and generate the information manually.

Besides giving route information for unfamiliar trips, navigation functions also provide traffic information and in case of congestion along the route, propose routes that avoid the congested road. This dynamic routing function is useful for familiar and for unfamiliar trips and should result in less time spent in congestion on highways. This effect of a navigation function is analysed by comparing the time spent in congestion for the different conditions. Further evaluation is difficult, because in the data logging no signal is available that codes whether the dynamic routing function offered a new route to the driver and whether that offer was accepted or declined. It might be possible to infer from the route taken (leaving the highway for a certain amount of time and then returning to the highway) that a detour has been taken, probably to avoid a traffic jam. For that detour, distance and travel time can be calculated. But that information is not enough to evaluate the effect of the dynamic routing function because it is not known, how long staying on the direct route would have taken. Instead, usage and evaluation of the dynamic routing function is assessed in the questionnaires. This information will be used to interpret results regarding the time spent in congestion.

### 5.3 Direct traffic efficiency effects – modelling approach

In Figure 17 the modelling approach is illustrated. The modelling approach – to calculate the effects on travel times – is used for three functions: ACC, SL/CC, and FEA. Two simulation tools are used: PELOPS (IKA) and ITS Modeller (TNO). ACC and FEA are modelled in PELOPS and SL/CC is modelled in the ITS Modeller. Descriptions of the ITS Modeller and PELOPS, their inputs and outputs, and a brief comparison between the models are given in Annex 4.

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\(^5\) Drivers are instructed to press a certain button in the vehicle whenever the route is unfamiliar.
To model the functions, FOT data are needed. With respect to that, one remark needs to be made. The results of WP6300 on the use of the three functions are only available in August, while simulations start in May. These results can therefore not be used as input for the driver behaviour models. To calibrate the driver behaviour models, the part of the FOT data that is available in May will be used to make assumptions on the use of the functions which are used in the driver behaviour models. These will be checked with results of WP6300 on function use after the hypotheses have been tested.

Efficiency impacts assessment (modelling approach)

![Diagram showing data flow for efficiency impacts assessment](image)

Figure 17: Overview modelling approach for calculating direct traffic efficiency effects

Objective FOT data, such as speeds and accelerations are measurements from the CAN bus, video data, etc. Objective data could provide information on increase/decrease in exposure in a “within subject” setting, therefore the dotted line. Subjective FOT data are data acquired through questionnaires, interviews, etc.

**Data needs of the modelling approach**

The situational variables and part of the performance indicators that are needed for the modelling approach are already mentioned in the introduction (section 5.1) under ‘data needs’. For the modelling approach more performance indicators are needed, in order to be able to implement the functions in a simulation model. Some indicators are needed for the implementation of the function in the simulation model; others are needed for the implementation of the driver model in the simulation model. What is needed for simulation is the following (this will be specified in more detail further below):
o A functional specification of the function in terms of abilities, limitations, decision rules and strategies of the ITS sensors, actuators and communication devices under consideration
o Usage: activation and deactivation strategies of the driver, setting strategies
o Activation status and settings of the function
o Desired speed (it may be measured as the realized speed in free flow conditions)
o Acceleration as a function of time headway, speed difference with predecessor, and desired speed
o Realized speed
o (Share of) speed difference with predecessor
o Driver response and reaction to alarms
o Driver reaction time
o The frequency (times per km) of overtaking manoeuvres
o The frequency (times per km) of lane changing manoeuvres
o Share of lane change and overtaking duration
o Choice of driving lane (time evolutions and/or distributions)

The indicators above that are not already listed in the introduction (section 5.1) under ‘data needs’ are worked out below. It is possible that for some VMCs or some car types not all data are available\textsuperscript{6}. In that case the simulation team needs to find a solution for this, depending on the function. Not all data are equally important for every function.

Table 14 and Table 15, split per function. The set of performance indicators is split between the indicators that are needed for the application model (the implementation of the function in the simulation tool) in Table 14 and the indicators that are needed for the driver model in Table 15.

Table 14: Data needs of the application model

<table>
<thead>
<tr>
<th>Application model</th>
<th>Indicators</th>
<th>ACC</th>
<th>FEA</th>
<th>SL/CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rules for function switching on and off</td>
<td>Function description</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Speed boundaries (operational range of the function)</td>
<td>Function description</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Acceleration boundaries (operational range of the function)</td>
<td>Function description</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Acceleration path of the application</td>
<td>Acceleration, speed, position and following distance when function on (10 Hz, per road type).</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{6} This is certainly the case for the Italian VMC, where only subjective data are measured.
In fact the indicator needs for the application model means that we need a functional specification in terms of abilities, limitations, decision rules and strategies of the ITS sensors, actuators and communication devices under consideration (first bullet under ‘data needs’ in this chapter).

The specification of the data needs in the table below is for the combinations of situational variables as in the simulated scenarios, being road type (urban, rural and motorways), speed limit, traffic condition (free flow/congestion) and vehicle type (car/truck) (e.g. motorway with a 130 km/h speed limit, congested traffic for cars). The first section of the table lists the data needs for the baseline behaviour, the second part for the treatment behaviour. Generally a distribution is needed, but sometimes the situation before or after an event is required. The number of required events per combination of situational variables should be determined by the simulating organisation (TNO or IKA) and the VMC, based on how much events are required and what is a feasible amount of data. This accounts also for the exact format in which the data can be provided in the most practical and feasible way.

Table 15: Data needs of the driver model

<table>
<thead>
<tr>
<th>Driver model</th>
<th>Indicators</th>
<th>ACC</th>
<th>FEA</th>
<th>SL/CC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calibration of normal driver/baseline parameters – driving without function</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desired speed</td>
<td>Free flow speed distributions</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Desired following distance</td>
<td>Following distance distributions</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Acceleration</td>
<td>Acceleration distribution</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Actual speed</td>
<td>Speed distributions (based on speeds measured with 10 Hz)</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Speed difference with predecessor</td>
<td>Distributions speed difference with predecessor</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>The frequency (times per km) of lane change manoeuvres</td>
<td>Lane change events per km</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>The frequency (times per km) of overtaking manoeuvres</td>
<td>Overtaking events per km (if available, else use lane change as indicator)</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Compliance with speed limits</td>
<td>Distributions of difference between speed and speed limit</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Choice of driving lane</td>
<td>Distribution of driving lane for different road types by number of lanes</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Anticipation on vehicles merging before driver</td>
<td>Following distance 30 seconds before vehicle merging in front</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><strong>Driving with function</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activation status and settings of the function</td>
<td>Function on/off/active/speed and following distance setting</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Desired speed</td>
<td>Distributions free flow speed</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Acceleration</td>
<td>Acceleration distributions</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Speed difference with predecessor</td>
<td>Distributions speed difference with predecessor</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Set speed</td>
<td>Speed setting</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Actual speed</td>
<td>Speed distributions</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
## Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment

<table>
<thead>
<tr>
<th>Driver model</th>
<th>Indicators</th>
<th>ACC</th>
<th>FEA</th>
<th>SL/CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set time headway (THW)</td>
<td>THW setting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaction time after function switch off (when braking of the driver is necessary due to limitations of the function)</td>
<td>Time between function switch off and braking i.c.o. automatic switch of events</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>The frequency (times per km) of lane change manoeuvres</td>
<td>Lane change events per km</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>The frequency (times per km) of overtaking manoeuvres</td>
<td>Overtaking events per km (if available, else use lane change as indicator)</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Choice of driving lane</td>
<td>Distribution of driving lane for different road types by number of lanes</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Rules for driver switching on and off</strong></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Traffic density when driver switches off</td>
<td>Traffic condition and following distance for the events when driver switches function off manually</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desired acceleration driver lower or higher than function acceleration</td>
<td>Acceleration, speed, position and following distance, speed difference (at moment of driver switch off and 10 seconds before and after)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switch on after ?? time and not braking</td>
<td>Acceleration, speed, position and following distance, speed difference (at moment of driver switch on and 10 seconds before and after).</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporary adaptation of the speed (overruling ACC/CC)/km</td>
<td>Acceleration, speed, position and following distance, speed difference (at moment of driver changes speed and 10 seconds before and after).</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adaptation of the following distance (overruling ACC)/km</td>
<td>Acceleration, speed, position and following distance, speed difference (at moment of driver changes following distance and 10 seconds before and after).</td>
<td></td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

We assume that data are available as stated above and in section 5.1. The methodology for the modelling approach for calculating direct traffic effects is for most steps the same as for the linear approach. Two steps are different: step (2) and (3) in the linear approach (calculating speed difference and travel time difference) are replaced by a simulation step, see blue box in Figure 17. Some steps are very slightly adapted due to this change. The simulation step is as follows:

Calculate difference in travel time from objective FOT data through simulation between different scenario’s (for example varying the penetration of equipped vehicles or the traffic demand), see Figure 17. This step consists of six sub steps:

1. Building application model
2. Building behavioural model
3. Defining experimental set-up
4. Carrying out simulations
5. Analysing simulation results
6. Validating the behaviour of the application model and behavioural model against the FOT data.
The influence of situational variables is not modelled directly. This is taken into account in some way in the simulation (see later in this document).

After simulation, hypothesis 4 (‘the amount of recurrent delay (e.g. daily congestion in peak hours) in the network will decrease’) can be tested.

After simulation, research question 1a (‘what is the impact of the function on average network speed’) can be answered.

After simulation, research question 2 (‘what is the impact of the function on amount of delay’) can be answered.

After simulation, research question 5 (‘what is the impact of the function on section performance (vehicles per km)’) can be answered.

In the following subsections the simulation steps are described, and the scaling up step is described in more detail.

5.3.1 Simulation step 1: application models

In the first simulation step the application model is built, that means that the function under consideration is implemented in the simulation model. This means that for the functions that are in the modelling approach, a description has to be made of how the function is implemented in reality. To be able to build the application model we need a functional description of the function in terms of abilities, limitations, operating conditions of the function, possible settings, decision rules and strategies of the ITS sensors, actuators and communication devices under consideration. Full descriptions of the functions can be found in [20].

Besides the function description other information can be used for building the application model, such as literature, other evaluations, and information from technical tests.

Also important are the possibilities in the simulation model; it may not be possible to model all features of the function in the simulation model.

In the following three subsections the application model is described for the three functions.

5.3.1.1 ACC

In the following, the implementation of the ACC+FCW in PELOPS is explained. This covers the description of the function itself as well as the function boundaries and the rules for function switching on and off.

There are different control strategies an ACC function can pursue. Quite often PID (proportional integrate derivative) controllers are used for distance control in ACC functions. These controllers are set up relatively simple and thus can be implemented on microcontrollers easily. Another advantage is the frequent use of PID controllers which causes the availability of numerous approaches to determine the control parameters. Use of these controllers in ACC functions with certain functionalities may not be sufficient as differences arise in the control of two variables such as distance and velocity. ACC functions thus utilize cascaded controllers. A cascade control function is a multiple-loop function where the primary variable is controlled by adjusting the setpoint of a related secondary variable controller. The secondary variable then affects the primary variable through the process. Figure 18 visualizes a simple cascaded controller for an ACC function.
Input variables like velocity, relative velocity and distance to the preceding vehicle are used to determine the desired pedal position in consideration of the environmental conditions (road resistances) and the driver’s desired values (maximum velocity and acceleration). Acceleration profiles or acceleration maximum especially regarding transients between driving situations may be adjusted dependant on the situation with a limitation of the minimum of the desired accelerations, $a_{\text{desired,d}}$ and $a_{\text{desired,v}}$ from the velocity deviation and distance deviation. The control of the proportion of $k_v$, $k_d$ (damping of the control loop) and $k_d$ (stiffness of the control loop) enables the consideration of swing-in manoeuvres of near vehicles with little differential-velocity: By reducing the reinforcement $k_d$ of the distance deviation for a period of time an unnecessary strong braking manoeuvre will be avoided in this situation, because the velocity of the vehicle, which performs a swing-in manoeuvre, is determined instead of the short distance, which is temporarily measured between both vehicles. The time gap $t_{\text{time gap}}$ is important. It will be adjusted by the driver between one and two and a half seconds according to the make of car. In order to realize the given velocity and acceleration independently from signal noise and/or influences by road gradients, additional weight etc., the acceleration controller $F_R$ has to feature at least PI-control response. The parameters $k_{v1}$, $k_{v2}$, $k_{t_{\text{time gap}}}$, $a_{\text{min}}$, $a_{\text{max}}$ enable to set nearly every controller characteristic.

The control concept of the ACC function described above is not sufficient in every driving situation because control parameters have to be adjusted to each situation. Thus ACC functions use situation classifiers to detect driving situations such as approaching, following or cut in situations. Therefore vehicle data and information from the distance sensor are used. Based on these classifications the control parameters are derived to ensure comfort as well as a safe distance to the front vehicle.

Table 16 gives an overview on the chosen values for the function boundaries/parameters.

<table>
<thead>
<tr>
<th>ACC function boundaries/parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_{\text{min}}$</td>
<td>30 [km/h]</td>
</tr>
<tr>
<td>$v_{\text{set,min}}$</td>
<td>30 [km/h]</td>
</tr>
<tr>
<td>$v_{\text{set,max}}$</td>
<td>180 [km/h]</td>
</tr>
<tr>
<td>$a_{\text{min}}$</td>
<td>-2.5 [m/s²]</td>
</tr>
<tr>
<td>$a_{\text{max}}$</td>
<td>3.0 [m/s²]</td>
</tr>
</tbody>
</table>
For the vehicles that are equipped with ACC, a virtual sensor will be mounted on that vehicle. The parameterisation is adapted to a long range radar sensor commonly used for ACC: 150 m detection range and ±10 ° azimuth field-of-view angle. White noise is used for modelling the measurement errors (e.g. in distance and relative velocity).

The assumptions that have been taken for modelling the function driver interactions (switching on and off the function, temporary overriding ACC, changing the set speed or set distance, etc.) will be described in subsection 5.3.2.2.

5.3.1.2 SL/CC

The two functions – speed limiter and cruise control – help the driver to manage the speed and cannot be used simultaneously. The speed limiter limits the speed below the selected value. The cruise control regulates the speed at the programmed value. For both functions the characteristics of the application model are described below: (de)activation rules (both by driver and by function), possibility of overriding (SL), de/acceleration controller (CC), speed range, and de/acceleration limits (CC).

Speed limiter function
The speed limit value is preset by the driver during the function activation. The speed limiter function can be off or on. When it is on, it can be active or inactive. When it is on and active, it is only restrictive when the speed of the car reaches the programmed value. When it is restrictive, it can be temporarily overridden.

- The minimum value of the speed limit is 30 km/h.
- To turn on the function, the driver has to switch a button. By default, the function is inactive and no speed limit is preset.
- In order to activate the function, the driver has to push “+” or “-” to select the current speed as the new speed limit.
- To deactivate the function, the driver has to push the related deactivation button. During the deactivation, the current speed limit is kept in memory.
- In order to reactivate the function, the driver has to push “+”, “-” or “R” button. The “+” and “-” buttons select the current speed as a new speed limit, and the “R” button recalls the previous speed limit in memory.
- To turn off the function, the driver has to handle the function switch to the position “off”. The function is automatically turned off when the driver turns the engine off.
- The driver can change the speed limit at any time during the drive, when the function is activated, by pushing the “+” or “-” buttons.
- When the function is restricting the car speed, it can be temporarily overridden by pushing the accelerator pedal deeply, for example for overtaking. In this case, the function is temporarily deactivated, but will return to active mode without any driver actions on the buttons after this acceleration phase, when the speed of the car is below the speed limit.

Cruise control function
The cruise control function maintains a constant speed without any manual control by the driver. This speed is programmed by the driver. The function can be off or on. When it is on, it can be active or inactive. When it is active, it can be temporarily overridden.
The function can only be **activated** when the **speed** is above 30 km/h and the **last gear box positions (position 4 and 5)** are engaged.

- To **turn on** the function the driver has to switch the control (button) in cruise control position. The function is inactive now (as no speed is programmed).
- The driver can **activate** the function with “+” or “-” button to set the programmed speed with the current speed of the car.
- Several actions can **deactivate** the function:
  - The driver pushes the deactivate button
  - The driver pushes the brake pedal
  - The driver pushes the clutch pedal
  - If EPS or ASR are activated by themselves
  - If gear box is in neutral position

After the deactivation, the programmed speed is kept in memory.

- In order to **reactivate** the cruise control, the driver has to push “+”, “-” or “Resume” buttons:
  - Pushing “+” or “-” programs a new speed: the current one
  - “Resume” uses the previous programmed speed

- The driver can change the programmed speed at any time during the drive, when the function is activated, by pushing the “+” or “-” buttons.

- By default, it is not necessary to handle the accelerator pedal. However, if the driver wants to drive above the programmed speed, the function can be temporarily **overridden** by pressing the accelerator pedal to gain speed. In this case, the function is temporarily deactivated. It will be automatically reactivated after this acceleration phase, when the speed of the car comes back below the programmed speed.

- To **turn off** the function the driver has to switch the control to the off position or can turn the engine off. In both cases, the programmed speed is erased from memory.

### 5.3.1.3 FEA

In simulation, there is no specific algorithm implemented for modelling the FEA. For modelling the function FEA, the driver behaviour is adapted, mainly the engine speed thresholds for gear shifting. Because this affects the behavioural model, details will be described in subsection 5.3.2.

### 5.3.2 Simulation step 2: behavioural models

The second simulation step contains a large bulk of the work: building the behavioural models (also called driver models). A behavioural model describes the behaviour of driver when driving with the function in his or her car. For the functions under research a behavioural model of the function needs to be implemented in the simulation model. To develop this behavioural model, FOT data are used, besides other sources such as literature and behavioural models that are already implemented in the simulation model. In general there are two options for developing this behavioural model. The first step however is to calibrate the behavioural model for the reference situation (non-equipped driving) with the FOT data. Afterwards one of the two options below can be used to develop the behavioural model for equipped driving.
Tuning parameters (‘recalibration’) in an existing model. If there already exists a behavioural model (for example the MIXIC model) that describes driver behaviour with the function well (this is an assumption!), the parameters of this model can be tuned according to data that come out of the FOT. A parameter is for example the intended (i.e., desired) speed that can be fed into a simulation model. Important here is to analyse the FOT data and the function under research thoroughly and try to understand all the dependencies. For example, when there are changes in speed and time headways, this can be caused by the change in speed or by the change in headways, or by another variable. Of course causation cannot be retrieved directly from the FOT data, but together with the function description a larger understanding can be reached.

It is possible that, besides calibration, some small other adaptations of the existing model are needed.

Training a black box model with the parameters that come out of the FOT. A black box model is a function of which there is no a priori information available. With an algorithm and FOT data a model can be trained. After training a black box model is able to generate output on its own. For example from position and acceleration at time t, it calculates position and acceleration at time t+1. This output can for example be an estimation of a certain variable over time. There are different types of black box models, for example Bayesian, Markov, neural networks, and partial least squares models. There are several open source packages for black box models in any programming language. The black box model needs to be coupled to a micro-simulation in some way at the end, offline or online.

Summarizing, the first option (tuning parameters) calibrates parameters of existing models to values found in the FOT, and the second option (black box model) is a model that generates output (for example acceleration, speed) itself by training with the FOT data.

In euroFOT, we will use the first approach. Main reasons for this are that our existing models are suitable for the euroFOT functions, and we have experience with the existing models. Black box is something which we have no experience with, and because it is a ‘black box’ not everything that happens in the model can be reasoned or inspected.

After the application model and behavioural model are built, the model is calibrated with data from the FOT. Calibration means fine tuning the model with data. After calibration the fine tuned model is validated with another set of data. Calibration is described further in subsection 5.3.2.1.

**Situational variables**

For every function one driver model is developed / used (of course with distributions and random variations in parameter values). In this driver model some situational variables are reflected such as road type, link versus intersection, and congestion versus free flow. However, the impact of situational variables on driving is not taken into account explicitly. For example weather and lightning are no variables in the simulation. To be more precise, there will not be special driver behaviour models for behaviour during night or rain. Initially, all data are used for building the behavioural model. Not-relevant situational variables are aggregated. For the relevant situational variables the share of presence of the different levels is checked. These different levels can be reflected with the same driver model (but with other (distributions of) parameters) in different scenarios. Via scaling up the different levels of situational variables are then taken into account.

A special situational variable is the status of the function (on/off). It is very much preferred to have this situational variable reflected in one driver model. Sometimes it is possible to work around this issue through penetration rates, or via boundaries / ranges of the function.
In the three subsections 5.3.2.2, 5.3.2.3 and 5.3.2.4 the behavioural models for the three functions are described.

5.3.2.1 Calibration of reference driver model (ITS modeller)

In the ITS Modeller the MIXIC driver model [24] is used. The parameters used in the MIXIC model are speed, speed predecessor, gap, etc. The MIXIC model will be calibrated on FOT data. States predicted by the model are compared with the observed states in the FOT data and the difference is minimized for the set of parameters. The calibration of the car-following baseline consists of the following steps:

- **Definition of car-following**
  Car-following is defined as driving closer than 60 meters behind the predecessor for more than 5 seconds consecutively.

- **Isolate car-following data parts from the FOT data (without function)**
  Data samples of car-following behaviour will selected from at least 10 different drivers with a total of over 2 hours.

- **Fitting of parameters**
  - **Desired headway (three parameters)**
  - **Desired acceleration (two parameters)**
  These parameters are fitted to the data by minimizing the difference between the model results and the measured FOT data for different values of the parameters.

  The response time is based on literature.

- **Comparison of fitted parameters with current settings**
  The difference between the fitted parameters and the current settings will be compared to find an explanation and decide which will be used for future studies.

- **Comparison of road capacities**
  The validity of the new driver model on a traffic flow level will be tested by comparing road capacities with real data or with the default driver model.

5.3.2.2 ACC

In this subsection, a description of the calibration of the driver model and a description of the adaptations needed for the implementation of the function ACC are given.

For calibrating the PELOPS driver model in both cases, driving with and without function, the parameters indicated in the beginning of this chapter (Table 14 and Table 15) will need to be extracted from the FOT data. The most important data needed for the calibration of PELOPS are the acceleration of the driver as a function of time headway, speed, speed difference, desired speed and traffic density. Therefore, these single parameters should be recorded in order to make possible the extraction of the above mentioned correlation. Besides that, data like driver reaction time, compliance with speed limits, etc. are used to adapt the PELOPS driver.

Concerning the interaction of the driver with the ACC function, assumptions for the following indicators have to be made, based on the FOT data:

- **Set time headway**
- **Change of the set speed**
- Change of the set time headway
- Reaction time after function switch off (due to function limitations)
- Rules for driver switching on and off
- Traffic density when driver switches off
- Desired acceleration driver lower than function acceleration
- Distance/TTC too small or too large
- Anticipation on vehicles merging before driver
- Switch on after ?? time and not braking
- Temporary adaptation of the speed (overruling ACC)

5.3.2.3 SL/CC

SL and CC can be implemented by adapting the longitudinal driver model in the ITS Modeller, the MIXIC model. This 'standard' longitudinal driver model is described in [24]. This longitudinal driver model is a set of sub-models in which desired accelerations (positive/negative) are determined for a given driver-vehicle-unit and for the given time instant. The longitudinal model calculates different accelerations based on limiting conditions such as the speed limit, the intended speed, the vehicle limitations, and returns the minimum as the final acceleration value. Using this value, the position and speed of the vehicle in the network is updated for the next time step.

Adaptation longitudinal driver model for SL/CC

In the ITS Modeller an adaptation of the longitudinal driver model to Speed Alert (a function that resembles SL) is available, as well as an adaptation to Advanced Cruise Control. Both these adaptations are useful for the implementation of the behavioural model of SL/CC.

For the Speed Alert function the distribution of the intended speed is changed in the ITS Modeller. For an earlier project this was based on literature. With the data from euroFOT this intended speed distribution can be calibrated and adapted, to describe the SL function. The FOT data needed are then speed distributions of the drivers.

SL can be validated based on distribution of the time headway, time to collision, and on compliance with the speed limit.

For Advanced Cruise Control the speed and distance to predecessor are set. For CC we can use the feature where the speed is set. With the data from euroFOT the speed distribution when CC is on can be used to calibrate the model. The FOT data needed are then speed distributions of the drivers.

CC can be validated based on distribution of the time headway and time to collision.

The calibration and modelling approach for CC and SL are listed in Table 17.

<table>
<thead>
<tr>
<th>Cruise Control</th>
<th>Speed Limiter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 For those equipped in future year, define <strong>percentage willing to use</strong> the CC-functionality <strong>frequently</strong></td>
<td>For those equipped in future year, define percentage willing to use the SL-functionality SL frequently</td>
</tr>
<tr>
<td>2 Define <strong>activation rule</strong> for those willing to use the CC frequently.</td>
<td>Define <strong>activation rule</strong> for those willing to use the SL frequently.</td>
</tr>
</tbody>
</table>
Hypothesis: activation only when unhindered driving:

*Predecessor THW > 7 seconds* &
*TTC > 15 seconds*

And within function boundaries CC

Hypothesis: activation only when driving near desired speed:

*Current speed > 0.95 * Desired speed*

Assumption: no behavioural change of desired speed due to available SL

### 3

Define **speed adaptation rule** when using CC

Hypothesis: speed changes (+/- by hand) are performed as if driver reacts with gas pedal. No change in cf-algorithm. Alternatively CC could result in more hysteresis (stay on one speed longer, then abruptly jump to another) or in adaptive speed with the gas pedal.

Define **speed adaptation rule** when using SL

Hypothesis: speed limiter changes (+/- by hand) are performed when entering road with small changed speed limit (10 km/h)

### 4

Define **deactivation rule** when using CC

Hypothesis: de-activation when it feels like approaching an uncomfortable/unsafe situation:

*Predecessor THW < 4 seconds* &
*TTC < 7 seconds*

And within function boundaries CC

Define **deactivation rule** when using SL

Hypothesis: de-activation performed when entering road with large changed speed limit >10 km/h change (instead of reducing limit with +/- button)

*Current speed > 1.1 * Desired speed*

And within function boundaries SL

For the steps in Table 17, the available data should be analysed and assumptions and hypotheses tested.

“Natural driving behaviour” within the ITS Modeller must be extended in case the (fuel efficiency) advantage of maintaining a constant speed by SL or CC must be shown. There are no indications in literature of other relevant traffic flow impacts when using a CC (or a voluntary SL).

- Instead of a constant (desired) speed the desired speed must be a little fluctuating (measurable during unconstrained driving conditions). This behaviour can possibly be derived from the data.
- Output of car-following algorithm is set to an acceleration of zero when driving with CC activated. Activation and deactivation rules must be calibrated as described in the table. The implemented rules will probably lead to a situation in which CC is only used under traffic conditions with I/C-ratio below 0.4.
- Output of car-following algorithm is set to an acceleration of zero when driving with SL activated at the desired set speed. Actually, that is what is done now in the model also. Activation and deactivation rules must be calibrated as described in the table.
- Assume that the “desired speed” –for a specific road- is not affected by using a CC or SL. (This assumption is hard to check with measurement data).
5.3.2.4 FEA

If the vehicle is equipped with a FEA function, it is assumed that this will lead to the following driving behaviour:

- The driver will shift to the next higher gear if the engine speed exceeds 2500 rpm (for vehicles with petrol engines) and 2200 rpm (for vehicles with diesel engines)
- The driver cuts off the engine if the vehicle is at standstill for more than 3 s (for instance in traffic congestion or at traffic lights)
- The driver will limit its acceleration (except when using kick-down)
- The driver will not exceed a speed of 120 km/h

The values and behaviour listed above will be checked with the FOT data and adapted if necessary.

5.3.3 Simulation step 3: experimental set-up

As mentioned already earlier, the evaluation has to provide the impact of the functions on traffic efficiency, in certain scenarios. This objective together with the application model and the behavioural model leads to an experimental set-up. The experimental set-up defines the input for the simulation model, the scale, penetration rates, and all other choices that have to be made with regard to the simulation. A good experimental set-up paves the road for a smooth simulation process and outcomes that can be used for cost benefit analysis.

The behavioural model describes how the driver interacts with the function under test; this influences some implementation and scenario choices (e.g. the choice of simulation model, or the travel choices that are taken into account). In the experimental set-up decisions are made on the following issues:

- Geographic region (network to be used)
- Time span (period, hours that are simulated)
- Year (base year or future year)
- Traffic demand (traffic volumes)
- Penetration rates

Also in the experimental set-up the scenarios that will be simulated are selected. Usually scenarios where a certain share of vehicles has the function under test are compared to a reference scenario, where none of the vehicles is equipped. Scenario choices also influence / determine which aspects of behaviour need to be included in the driver model.

5.3.3.1 ACC

ACC is expected to have an influence mainly on motorways and rural roads, on links (not on junctions). The effect of the function will probably vary for different traffic volumes.

PELOPS can not model junctions/intersections, i.e. no networks; this has to be taken into account.

For ACC the following experimental set-up is suggested:

- Geographic region: three simple road segments (urban, rural and motorway) with links. If the FOT data show no effect of ACC on urban roads, then this road type can be left out of the simulation.
- Time span (period): not important, this is already taken aboard in traffic demand
5.3.3.2 SL/CC

SL is expected to work on all road types, and it will mainly influence situations where a certain share of drivers exceeds the speed limit (free flow, all road types), on links (not on junctions).

CC is expected to have an influence mainly on motorways and rural roads, on links (not on junctions). The effect of the function will probably vary for different traffic volumes. The effects are expected to be very small.

SL and CC are not active at the same time; one of them or none is active.

For SL/CC the following experimental set-up is suggested:

- Geographic region: three simple networks (urban, rural and motorway) with junctions (junctions will have an influence on the network effect). These networks need to be representative for Europe.
- Time span (period): not important, this is already taken aboard in traffic demand
- Year: base year (2010) and future year (2030). The year is not direct input to the simulation, but is described through traffic demand taking into account future predictions of road use, and through penetration rate. Other indicators, such as composition of the vehicle fleet, change in sensor functions, etc., are not varied with in the simulation.
- Traffic demand: two levels, free flow and high density. The boundaries between the levels have to be determined, as well as the possibility of a third level. The FOT data can be input for this.
- Penetration rate: 0%, low (20%), most probable (50%), high (100%)

When considering all options, there are $2 \times 2 \times 3 = 12$ scenarios for each network. Maybe some scenarios can be left out, for example for the 0% penetration rate combined with the future year, and for the 100% penetration rate compared to the base year. The reference scenario is the scenario with 0% penetration in the base year.

5.3.3.3 FEA

FEA is expected to have an influence mainly on rural roads and urban roads (gear shifts are not often performed on motorways, except in congested traffic), on links (not on junctions), and on hills (roads with upward gradients). The effect of the function will be larger in free flow situations than in high density situations. The expected influence of FEA is shown in Table 18.
Table 18: Expected influence of FEA in different situations

<table>
<thead>
<tr>
<th></th>
<th>Urban</th>
<th>Rural/Motorway</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Free flow</td>
<td>Dense traffic</td>
</tr>
<tr>
<td>Shifting gear at lower engine speeds</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Cutting off engine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Smoother acceleration</td>
<td>Yes</td>
<td>Probably depends on how dense the traffic is</td>
</tr>
<tr>
<td>Driving not faster than 120 k/h</td>
<td>Yes</td>
<td>Eventually depends on speed profile</td>
</tr>
</tbody>
</table>

PELOPS cannot model junctions/intersections, i.e. no networks. However, because there is no need to model intersections to analyse FEA, PELOPS can model amongst others traffic lights and tight bends, which is sufficient to produce realistic speed profiles of urban traffic.

For FEA the following experimental set-up is suggested:

- Geographic region: three simple road segments (urban, rural and motorway) with links. If the FOT data show no effect of ACC on urban roads, then this road type can be left out of the simulation.
- Time span (period): not important, this is already taken aboard in traffic demand
- Year: base year (2010) and future year (2030). The year is not direct input to the simulation, but is described through traffic demand taking into account future predictions of road use, and through penetration rate. Other indicators, such as composition of the vehicle fleet, change in sensor functions, etc., are not varied with in the simulation.
- Traffic demand: two levels, free flow and high density. The boundaries between the levels have to be determined, as well as the possibility of a third level. The FOT data can be input for this.
- Penetration rate: 0%, low (20%), most probable (50%), high (100%)

When considering all options, there are 2 x 2 x 3 = 12 scenarios for each network. Maybe some scenarios can be left out, for example for the 0% penetration rate combined with the future year, and for the 100% penetration rate compared to the base year. The reference scenario is the scenario with 0% penetration in the base year.

5.3.4 Simulation step 4, 5 and 6: carrying out simulations, analysing results and validating models

This subsection briefly describes the last three simulation steps: carrying out simulations, analysing results and validating models.
Carrying out simulations
For each scenario, a number of runs are performed (with different random seeds). In this way outliers can be recognized. The number of runs that need to be carried out depends on the simulation model and the function and scenarios that are implemented. We propose to have at least five runs per scenario. Depending on the output that is needed the relevant output files or evaluation models are specified.

Analysing results
The output files are analysed and presented in a clear, schematic way. This can be for example per penetration rate, per demand type, per road type, etc. This depends on the function and scenarios. At least the outputs needed for the next step (scaling up) need to be presented. For traffic efficiency those are travel times. Furthermore, the indicators that are in the research questions (see subsection 5.1.2) should be presented:

- average network or journey speed
- amount of delay
- variation in travel times
- network performance (vehicle km travelled), per road category
- section performance (vehicles per h)

Validating models
In this step the application model and behavioural model are validated. Part of the FOT data are kept back to validate these models. This means that for all the indicators part of the data can be kept back, or for part of the indicators all data can be kept back. For the ITS Modeller for example time headways or time to collisions can be kept back completely, and used for validation.

Following up on Table 15 under ‘calibration of normal driver/baseline parameters’, for all functions the desired speed and desired following distance could be used as input for the models, and the other indicators (acceleration, actual speed, etc.) could be used as validation.

5.4 Indirect traffic efficiency effects
Indirect traffic effects are the changes in amount of accident related congestion, based on changes in number of accidents. If accidents are prevented, this means a certain amount of accident related congestion is also avoided. In Figure 19 the approach for calculating indirect traffic effects is illustrated. This approach can be applied to all functions. The safety impact assessment produces outputs in terms of changes in accidents at the EU level. Via the spread sheet that was developed in the eIMPACT project for safety impacts, the impact of functions on accident related congestion is calculated.
To calculate the indirect traffic efficiency effects the approach of eIMPACT is followed, see [22]. This approach estimates the indirect efficiency effects by assigning a cost for congestion caused to each severe accident. The input for this approach consists of the estimated number of accidents with and without the safety function as reported by the safety impact analysis. Avoided accidents lead to benefits in terms of reduced congestion costs. As effects may depend on for example road types and times of day that a function is effective, it will be determined for each function separately which reduction in congestion costs can be expected from avoided fatalities and injuries.

Deliverable 3 of the eIMPACT project (Methodological framework and database for socio-economic evaluation of Intelligent Vehicle Safety Systems [23]) gives estimates for the average avoided costs per avoided accident (see Table 19). The values are valid for 2005.

Table 19: Average avoided costs per avoided accident [23]

<table>
<thead>
<tr>
<th>Accident with</th>
<th>Avoided congestion costs (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatality</td>
<td>15,500</td>
</tr>
<tr>
<td>Injury</td>
<td>5,000</td>
</tr>
</tbody>
</table>

These are average costs, based on the distribution of accidents over road types and periods of the day in 2005. However, road type and the time of day at which an accident occurs affect the accident costs. Therefore, it is taken into account where and when the functions are expected to be the most effective.

Figure 20 below shows how the indirect effects are calculated in eIMPACT and which data are available / needed to do that. For each function, the safety impact assessment produces the changes in the number of accidents with (a) fatalities and (b) injuries, per road type, and probably split out by several more situational variables. The safety impact assessment probably produces no specific information about the distribution of avoided accidents over the day, but assumptions about the effectiveness of the functions in different periods of the day are made by the safety impact assessment, based on the description of the functions and factors identified in the safety impact assessment (e.g. by comparing effectiveness factors for the day and night period).

When the avoided accidents are divided over road type and period of the day, the numbers can be multiplied by the average avoided costs per avoided accidents for the relevant road types and periods of the day. As these costs are only available as averages (for accidents with fatalities and accidents with injuries respectively), the costs are disaggregated to obtain costs per road type and period of the day. This means that a new table is estimated with...
costs split out by road type and time of the day. Assumptions for that can be made based on available statistics on congestion (costs). For instance, a queue caused by a fatal accident generates higher congestion costs in the morning (peak hour) than at night. Also, on motorways congestion costs will be much higher than on rural roads, because of the higher traffic flows. In the eIMPACT project this table has already been made, see later in this chapter.

If the safety impact assessment does not provide assumptions on the distribution of avoided accidents over the day, the average avoided congestion costs will be used for the calculations.

### PER SELECTED SYSTEM:

<table>
<thead>
<tr>
<th>From WP3300:</th>
<th>From WP2000 (D3):</th>
</tr>
</thead>
<tbody>
<tr>
<td># of avoided fatalities &amp; injuries, on:</td>
<td>Average avoided costs per avoided accident:</td>
</tr>
<tr>
<td>- motorways</td>
<td>-15.500€ / accident with fatalities</td>
</tr>
<tr>
<td>- urban roads</td>
<td>- 5.000 € / accident with injuries</td>
</tr>
<tr>
<td>- rural roads</td>
<td></td>
</tr>
</tbody>
</table>

**Assumptions of distribution over the periods of the day**

**Expected shares of accidents per road type and for each of the 4 periods of the day:**
- motorway
- urban road
- rural road

**Assumptions of costs in different periods of the day**

**Multiplication of relevant shares and costs**

**Avoided congestion cost by road type and period**

**Total avoided costs for the selected system**

Figure 20: Calculation of indirect effects

Avoided congestion costs are defined for twelve different scenarios (four periods of the day, on three road types), for accidents with fatalities, and for accidents with severe injuries.

The costs of a combination of location and time of day must depend on the probability of the occurrence of congestion due to an accident on that road type in that period. The estimations are based on statistics on accident and congestion occurrence over the day, and the following considerations:

- In morning and evening peaks the traffic flows mainly consist of traffic that has high value of time such as commuters and freight traffic. Economic damage due to considerable time losses is therefore likely to occur. In addition, fatal accidents will lead to considerable congestion on most motorways and some rural roads in peak hours. Also, in city networks high traffic loads will easily fill the area around the
accident and consequently block other crossings. Even though most urban networks are quite dense, it is unlikely that traffic can be easily rerouted during busy periods.

- In off-peak hours, congestion may also arise due to fatal accidents. However, traffic in off-peak hours will have lower values of time, and the impact will be less because of lower flows. In city centres, traffic can more easily be rerouted through the dense network, leading to considerably less congestion costs.

- At night traffic volumes are very low, so no significant reduction in congestion is expected then.

These considerations lead to a disaggregation of the average congestion costs as given in Table 20.

Table 20: Congestion costs due to accidents with fatalities and severe injuries over location and time of day.

<table>
<thead>
<tr>
<th>Location</th>
<th>Function</th>
<th>Fatalities</th>
<th>Queuing costs (EUR)</th>
<th>&quot;Share&quot; in average</th>
<th>Injuries</th>
<th>Queuing costs (EUR)</th>
<th>&quot;Share&quot; in average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways</td>
<td>morning peak</td>
<td>0.9%</td>
<td>103438</td>
<td>925</td>
<td>1.0%</td>
<td>25715</td>
<td>257</td>
</tr>
<tr>
<td></td>
<td>evening peak</td>
<td>1.4%</td>
<td>103438</td>
<td>1478</td>
<td>1.7%</td>
<td>25715</td>
<td>437</td>
</tr>
<tr>
<td></td>
<td>night</td>
<td>1.9%</td>
<td>20688</td>
<td>403</td>
<td>1.8%</td>
<td>5143</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>rest of the day</td>
<td>3.5%</td>
<td>51719</td>
<td>1808</td>
<td>3.8%</td>
<td>12857</td>
<td>489</td>
</tr>
<tr>
<td>Rural roads</td>
<td>morning peak</td>
<td>6.5%</td>
<td>21715</td>
<td>1421</td>
<td>3.8%</td>
<td>8098</td>
<td>308</td>
</tr>
<tr>
<td></td>
<td>evening peak</td>
<td>10.5%</td>
<td>21715</td>
<td>2270</td>
<td>6.5%</td>
<td>8098</td>
<td>526</td>
</tr>
<tr>
<td></td>
<td>night</td>
<td>14.3%</td>
<td>2895</td>
<td>413</td>
<td>6.7%</td>
<td>1080</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>rest of the day</td>
<td>25.6%</td>
<td>14477</td>
<td>3703</td>
<td>14.5%</td>
<td>5398</td>
<td>783</td>
</tr>
<tr>
<td>Urban roads</td>
<td>morning peak</td>
<td>4.1%</td>
<td>13096</td>
<td>534</td>
<td>7.3%</td>
<td>4883</td>
<td>356</td>
</tr>
<tr>
<td></td>
<td>evening peak</td>
<td>6.5%</td>
<td>13096</td>
<td>853</td>
<td>12.5%</td>
<td>4883</td>
<td>610</td>
</tr>
<tr>
<td></td>
<td>night</td>
<td>8.9%</td>
<td>2619</td>
<td>233</td>
<td>12.8%</td>
<td>977</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>rest of the day</td>
<td>15.9%</td>
<td>9167</td>
<td>1460</td>
<td>27.6%</td>
<td>3418</td>
<td>943</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVERAGE COSTS</td>
<td></td>
<td></td>
<td>EUR 15,500 per accident with fatality</td>
<td>EUR 5,000 per accident with injury</td>
<td>100.0%</td>
<td>100.0%</td>
<td></td>
</tr>
</tbody>
</table>

1) Based on: [SafetyNet, 2007] and Dutch accident statistics.

To summarize, below the input and output for the assessment of indirect traffic effects are given.

**Input**

To calculate indirect traffic effects, the outcomes of the safety impact assessment are needed. This means the change in absolute number of injuries and fatalities per year at the EU level, for the different scenarios (compared to the reference scenario), for each function.

These indicators need to be specified according to two situational variables: road type (motorway, rural road, urban road) and time of day (morning peak, evening peak, night, and rest of the day).

**Output**

The output of the impact assessment of the indirect traffic effects are the avoided congestion costs per function, for the different scenarios (compared to the reference scenario) on a yearly basis, at the EU level. This is direct input for the cost-benefit analysis.

After calculation of the indirect traffic effects, hypothesis 5 (‘the amount of incidental (accident-related) delay in the network will decrease’) can be tested.
6 Environmental impacts

6.1 Introduction

In chapters 1 and 2 of this document the introduction to the assessments and the general set-up of the assessment methodology are described. In this chapter the methodology for assessing environmental impacts is described. The evaluation on environment will be carried out for all functions and test sites, by the corresponding Vehicle Management Centres (VMCs). Key questions in the methodology (as stated in a general way in the introductory chapter) are:

- What data are needed for carrying out the environmental impact assessment?
- What steps need to be taken in the environmental impact assessment, or: how to calculate the environmental impacts?
- What are the outputs the environmental impact assessment needs to deliver?

This introductory section describes an overview of the environmental impact assessment including inputs and outputs (6.1.1), required performance indicators, research questions and hypotheses (6.1.2), a brief work process for the environmental impact assessment including steps, roles of partners and timeline (6.1.3) and outline of the rest of this chapter (6.1.4).

6.1.1 Overview environmental impact assessment

The functions tested in euroFOT can have an impact on the environment in various ways. During the environmental impact assessment the following impacts are considered:

- Changes in the number of kilometres driven: in total and distribution over road types
- Changes in average speeds
- Changes in variation in speed (homogenization)
- Changes in amount of congestion
- Changes in fuel consumption
- Changes in CO$_2$ emissions

The euroFOT data allows detailed assessment of environmental effects, because it includes very detailed information on speed and acceleration and fuel consumption. Also, the data can be linked to various situational variables (road types, weather, etc.). For higher penetration rates, similar data can be obtained from micro-simulation models, see section 5.3. The environmental impact assessment will provide input for the cost-benefit analysis (CBA). The CBA in euroFOT requires information about the costs and benefits of the functions at the EU level. The following quantified environmental impacts will be provided to the CBA (at the EU level):

- **Direct effects**: change in fuel consumption and CO$_2$ emissions caused directly by a change in tactical driver behaviour (e.g. speed, acceleration)
- **Indirect effects**: change in fuel consumption and CO$_2$ emissions caused by a change in kilometres driven (for example less congestion due to less accidents)

The environmental impacts are based on the traffic efficiency and safety impact assessment.

Inputs for the environmental impact assessment are the FOT results coming from the data analysis. Performance indicators that are needed are specified in the next section, situational variables are already given in chapter 2.
This chapter describes how to go from calculated performance indicators to tested hypotheses, answered research questions and quantified environmental impacts. This includes translating small scale results to the EU level and considering different scenarios (varying for example penetration rates and traffic demand). Each section describes the methodology and tools that will be employed, and the inputs/outputs of the assessment.

As a consequence of the two issues mentioned above, the following two calculation methods will be used to obtain the desired results: a **linear approach** and a **modelling approach**. The linear approach uses FOT data directly and effects are scaled up to EU level via situational variables. The modelling approach uses FOT data as input for traffic simulations and an emission model. With a traffic simulator the interaction between equipped and non-equipped vehicles can be modelled (see section 2.4).

To summarize, in Figure 21, a high level overview of the steps before, in, and after the environmental impact assessment is given. A certain function is tested in a FOT and produces FOT results (performance indicators, situational variables). Then the environmental impact assessment starts: direct effects and indirect effects are calculated. Direct effects can be calculated by a linear and by a modelling approach. Indirect effects are calculated via the traffic efficiency impact assessment. Results of the traffic efficiency impact are partly based on the results from the safety impact assessment (reduction in accident related congestion) so these are also taken into account in the environmental impact assessment. Direct and indirect effects together form the total environmental impacts on fuel consumption and CO₂ emissions. Results of the environmental impact assessment provide input for the cost-benefit analysis. Here the environmental impact assessment ends. At several points in the overview figure, external data may serve as additional input. This is not displayed in the figure.

![Figure 21: Overview environmental impact assessment](image)

The three red boxes in Figure 21 are worked out later in this chapter. More extensive figures are then given with the steps that need to be taken.
Overview environmental impact assessment per function

The descriptions of the functions tested in euroFOT can be found in [20].

Table 21 presents how the different functions need to be assessed. It shows for each function in which categories (direct and indirect traffic efficiency) an impact can be expected and needs to be assessed. It also shows which assessment approach (linear or modelling) is the most applicable one. Check marks indicate the impacts that are relevant and therefore need to be assessed. Check marks between brackets indicate that this impact may need to be assessed if the FOT data show an effect of the function on regular driving behaviour. In the last two columns the most applicable assessment approach is indicated. For all functions, an assessment by the linear approach is possible to find non-interaction effects. This is not specifically indicated in the table unless no interaction effects are expected.

Table 21: Functions and types of environmental assessment

<table>
<thead>
<tr>
<th>Function</th>
<th>Indirect effects on environment</th>
<th>Direct effects on environment</th>
<th>Linear approach</th>
<th>Modelling approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>CSW</td>
<td>✓</td>
<td>Not enough data</td>
<td>✓</td>
<td>Not enough data</td>
</tr>
<tr>
<td>SL/CC</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>LDW</td>
<td>✓</td>
<td>(✓)</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>BLIS</td>
<td>✓</td>
<td>(✓)</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>SafeHMI</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Depending on whether a change in speed/speed profile can be observed in the data</td>
</tr>
<tr>
<td>FEA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Clarification of available data required</td>
</tr>
<tr>
<td>IW</td>
<td>✓</td>
<td>(✓)</td>
<td>✓</td>
<td>-</td>
</tr>
</tbody>
</table>

6.1.2 Research questions, hypotheses and performance indicators

Earlier in the project research questions and hypotheses for the evaluation are formulated. The following research questions are relevant for the environmental impact assessment:

What is the impact of a certain function on:

1. Fuel consumption per km
2. CO₂ emission per km

In Table 22 below, the hypotheses relevant for efficiency are specified. For each hypothesis, it is indicated for which function groups the hypothesis is relevant, and whether it can be tested by the linear approach or the modelling approach. The function groups contain the following functions:

- Longitudinal
  - ACC
  - FCW
  - SL/CC
- Lateral
  - LDW
Table 22: Global assessment environmental hypotheses, relevance for the three function groups and choice in approach (linear or modelling)

<table>
<thead>
<tr>
<th>Nr</th>
<th>Hypothesis</th>
<th>Function group</th>
<th>Linear approach</th>
<th>Modelling approach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Longitudinal</td>
<td>Lateral</td>
<td>Traffic simulation</td>
</tr>
<tr>
<td>1</td>
<td>The average speed will decrease</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>The number of trips made will increase</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>The number of vehicle km travelled will increase (to be tested per road category)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>The fuel consumption will decrease</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>The CO₂ emissions will decrease</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

In the rest of this chapter, it is indicated at which moment and during which analysis the research questions and hypotheses can be tested or answered.

For the calculation of direct and indirect effects and for both approaches, certain data are needed: performance indicators and situational variables. The situational variables are the same for the linear approach and the modelling approach and are already given in section 2.3. More performance indicators are needed in the modelling approach than in the linear approach, because of the additional usage of emission models. The complete list of performance indicators for the modelling approach is given in section 6.3. For both approaches it is assumed that from data analysis the following performance indicators have been obtained:

- Average speed (km/h)
- Speed profile (min. 1Hz)
  - This will be provided from the traffic efficiency simulations since the FOT data do not include the indirect effects
- Fuel type
- Fuel consumption per km
- CO₂ emissions per km
- The number of km driven per day for each vehicle
- Data for scaling up (see chapter 7)
6.1.3 Work process

Data analysis is done by the VMCs and is finished when the environmental impact assessment starts. IKA provides the methodology for the environmental impact assessment and supervises the analysis. The VMCs do the actual implementation and analysis: testing of hypotheses and carrying out of the environmental impact assessment, using the methodology described in this document.

As stated earlier in this chapter, the modelling approach for calculating direct environmental effects makes use of micro-simulation models and an emission model. These models are available at TNO and IKA (both German1), but not at the VMCs themselves. IKA and TNO will carry out traffic simulations for some functions (see Table 21) for the VMCs, and TNO carries out simulations with their emission model (VERSIT+). In this chapter it is defined which information is needed from the other VMCs in order to conduct the environmental impact assessment.

The functions that are indicated for the modelling approach are ACC, SL/CC and FEA. SafeHMI was originally selected for the modelling approach, but this will not be possible because of limited data loggings. In Table 23 an overview of the functions for the modelling approach is given, including the corresponding VMCs and responsible traffic simulation partner.

To ensure that VMCs need to deliver data only to one partner (TNO or IKA), in order to carry out the traffic efficiency as well as the environment analysis the same division with respect to functions and partner for modelling has been chosen for the traffic efficiency as well as the environmental analysis (ACC & FEA (IKA) and SL/CC & SafeHMI (TNO)). Hence additional effort for data exchange is avoided. Fuel consumption and emissions of CO₂ are obtained through post processing with VERSIT+. More information on VERSIT+ is included in Annex 4.

Table 23: Overview of functions for the emission modelling and the corresponding partners responsible for the modelling

<table>
<thead>
<tr>
<th>Function</th>
<th>VMC</th>
<th>Cars or trucks</th>
<th>Simulation by IKA or TNO</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC</td>
<td>German 1, Sweden</td>
<td>Cars</td>
<td>IKA</td>
</tr>
<tr>
<td>ACC</td>
<td>German 1, Sweden</td>
<td>Trucks</td>
<td>IKA</td>
</tr>
<tr>
<td>SafeHMI</td>
<td>German 2</td>
<td>Cars</td>
<td>TNO (if possible because of limited data loggings)</td>
</tr>
<tr>
<td>SL/CC</td>
<td>France</td>
<td>Cars</td>
<td>TNO</td>
</tr>
<tr>
<td>FEA</td>
<td>Sweden</td>
<td>Trucks</td>
<td>IKA</td>
</tr>
</tbody>
</table>

6.1.4 Outline

In the next three sections the red boxes from Figure 21 are worked out: the methodology for the linear approach for calculating direct environmental effects is explained in section 6.2. The methodology for carrying out the modelling approach for calculating the direct environmental effects can be found in section 6.3. The methodology for calculation of the
indirect environmental effects is described in section 6.4. In Annex 4 descriptions of the simulation and emission models of TNO and IKA can be found, as well as a brief comparison between the models.

### 6.2 Direct environmental effects – linear approach

Direct environmental effects (changes in fuel consumption and CO₂-emissions) can be calculated by the linear approach: FOT data are used directly and effects are scaled up to EU level via situational variables. For three functions (ACC, SL/CC and FEA) additionally the modelling approach is applied (see section 6.3), since for these functions it is expected that equipped vehicles influence other road users and these functions can be modelled in micro-simulation models currently available and suitable for network analyses.

The linear approach will be applied to all functions (Swedish VMC – ACC (truck and passenger cars), IW (passenger cars), BLIS (passenger cars), LDW (trucks and passenger cars), FEA (trucks), German1 VMC – ACC (trucks and passenger cars), LDW (trucks and passenger trucks), German2 VMC – SafeHMI (passenger cars), French VMC – SRS (passenger cars)) and conducted by the VMCs itself. In Figure 22 the linear approach is illustrated.

![Diagram](image)

**Figure 22:** Approach for calculating direct environmental effects

Objective FOT data, such as speed and acceleration are collected from the vehicles’ CAN Bus. Objective data can provide information on increase/decrease in exposure in a “within subject” setting (the same group of participants first driving without the function, and then with the function), therefore the dotted line. Subjective FOT data are data acquired through questionnaires, interviews, etc.
The linear approach for calculating direct environmental effects is divided into eight steps and described in the following.

1. Check for which situational variables EU data are available with regard to mileage (this step needs to be carried out once for all functions and also for the traffic efficiency and the safety impact assessment) see Figure 22 input “other sources”. This information is also needed for the traffic efficiency analysis and can hence be used when defined for the traffic efficiency. For example, if there are no data on inclination available, it does not make sense to split performance indicators for this situational variable. To give an example, for a certain situational variable with 3 levels the following data should be available at the EU level:
   - Kilometres driven at level 1
   - Kilometres driven at level 2
   - Kilometres driven at level 3

   If no EU data are available for a certain situational variable, it depends on the relevancy checks of steps (2) and (4)/(5) what to do. If this situational variable is relevant (for speed or exposure) an assumption can maybe be made. If the situational variable is not relevant, it is not a problem.

   This step will be carried out by TNO and WP6500.

   For scaling up of the environmental effects EU data on fleet characteristics relevant to different EU countries are required.

   The following steps need to be carried out for every function separately.

2. Determine the fuel consumption per km between driving with function and driving without function from objective FOT data for (combinations of) situational variables. The emissions will be determined based on the fuel consumption.
   - Check which situational variables are relevant (i.e. the fuel consumption, speed difference differs depending on the level of the situational variable when comparing driving with function to driving without function)
   - Ideally, for the relevant situational variables also all combinations are researched. However, this takes more effort and time and data sets are smaller (less chance of significant results). Therefore, we will look at combinations of two situational variables at a maximum. This is only possible if there is European data available on these combinations, or if it is possible to make a reliable assumption.

Hypothesis E1 can be tested after Step 2:

Hypothesis E1: Function X decreases the fuel consumption

Step 3 and 4 are about exposure. It is very difficult to verify whether a change in exposure can be assigned to the function, or if it is a coincidence or due to other factors, such as seasonal effects. Therefore, only if the subjective data indicate a clear change in exposure, this change in exposure is calculated from the objective data and used in the analysis. Also, it will be checked if it is likely that the change in exposure can be assigned to the use of the function.

3. Check in subjective FOT data (questionnaires) if there is a significant change in exposure. This can be a change in total number of kilometres driven. It is also possible that there is no change in total number of kilometres driven, but a shift in the circumstances under which these kilometres were driven: a change in exposure for situational variables. For example more kilometres driven on motorways instead of on rural roads.
4. If the answer to (3) is ‘yes’, calculate the change in exposure for (combinations of) situational variables (so restricted to those found in (3)).
   
o Check which situational variables are relevant (i.e. for which situational variables there is a change in exposure when comparing scenario without function to scenario with function).

   o Ideally, for the relevant situational variables also all combinations are researched. However, this takes more effort and time and data sets are smaller (less chance of significant results). Therefore we will look at combinations of two situational variables at most. This is only possible if there are European data available on these combinations, or if it is possible to make a reliable assumption.

Hypothesis E2 can be tested after step 4:

<table>
<thead>
<tr>
<th>Hypothesis E2: The number of vehicle km travelled/per road type will increase</th>
</tr>
</thead>
</table>

5. Aggregate and (levels of) situational variables. Situational variables that are not relevant with respect to change in speed AND not relevant with respect to exposure, can be disregarded from now on (aggregated). This means that the data for these situational variables will be taken together.

What is left as separate situational variables are the ones that are relevant with respect to change in fuel consumption AND/OR exposure.

6. From change in exposure (4), taking into account the processing in (5), a database of kilometres travelled in EU for (combinations of) situational variables, and a penetration rate, calculate the kilometres travelled in the EU with and without the function, for (combinations of) situational variables. Of course this depends on the data found in (1).

**Note:** Step 1, 3, 4, 5 and 6 will be carried out for the traffic efficiency impact assessment and results will be used for the environmental assessment as well.

7. Based on the fuel consumption the rate of emissions per km is determined.

8. From (2), (6) and (7) the environmental impact in terms of fuel consumption (per km) and emissions (CO₂) are calculated. Again taking into account the processing in (5).

The scaling up step (6) is described in subsection 7.3.2.

What is needed for the steps that can be done already before FOT data are available is the following:

- Check whether all required information are available
- Check for EU data (statistics) on situational variables, fleet composition, emission factors for different EU countries
- Check what data are available in the database (when database set-up is ready). If not everything we need according to the steps above is available, an alternative needs to be searched.

Research question E3 and E4 can be tested after Step 8.

<table>
<thead>
<tr>
<th>Research question E3: What is the impact on fuel consumption?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research question E4: What is the impact on emissions (CO₂)?</td>
</tr>
</tbody>
</table>
Data collection on situational variables

The data on situational variables that will be collected at the EU level has a great influence on the impact assessment. Data will be collected through European and possibly national databases, making use of the work done in other European projects such as eIMPACT. We expect to find (at least for some countries) data on

- Road classification (road types)
- Weather – from meteorological institutes, using averaged data on for example rain hours
- Traffic situation (congestion / free flow)
- Lighting – using data on time of sunrise and sunset

We expect that it will be difficult to find data on number of lanes, road curvature, intersections, inclination and loading of trucks in these databases.

Most important is data on road classification: how many kilometres are driven on motorways, rural roads and urban roads.

If necessary, assumptions will be made on situational variables.

6.3 Direct environmental effects – modelling approach

In Figure 23 the modelling approach is illustrated. In a first step, traffic simulations (PELOPS and ITS Modeller) model interaction effects for higher market penetrations. FOT data (average speed, THW, system settings, etc.) serve as input for the simulations. The outputs of these simulations are speed-time profiles which are used in the second step to calculate emissions from the simulated speed-time profiles by the VERSIT+ emission model.

The modelling approach will be applied for the following three functions:

Traffic simulation by PELOPS and emission modelling by VERSIT+:

- ACC both trucks and passenger cars from the German VMC
- FEA only trucks from the Swedish VMC (if required data are available)

Traffic simulation by ITS Modeller (traffic simulation) and emission modelling by VERSIT+

- SL/CC only passenger cars from the French VMC

The traffic simulations will be conducted within the traffic efficiency impact assessment and needed input for the emission modelling will be provided to perform the environmental assessment. For this the same assumptions for the traffic efficiency as well as the environmental impact assessment will be made with respect to SVs, penetration rates etc. Thus the results of the traffic efficiency are applicable for the environmental assessment. IKA will provide the needed input (speed-time profiles at the defined penetration rates) for the emission modelling with VERSIT+ at TNO, after performing the traffic simulations for ACC and SL/CC.

The following figure presents the approach to be applied for modelling approach including the interaction between environmental and traffic efficiency assessment.
The modelling approach for the environmental assessment starts with the execution of traffic simulations. The traffic simulations require data collected within the field trial (average speed, THW, function settings etc.). The traffic simulations are applied for various penetration rates of equipped vehicles. These traffic simulations are conducted within the traffic efficiency impact assessment by means of the simulation models PELOPS and ITS Modeller. Further information on how the traffic simulations are going to be applied can be found in chapter 5.

The traffic simulation output is a speed-time profile for defined scenarios (penetration rates, road types and traffic states) which are defined in traffic efficiency assessment. The scenarios are selected in such manner that the results are consistent with the data available for scaling up to EU level from eIMPACT.
The speed-time profile is the input for the emission modelling in VERSIT+. The emission modelling will provide the rate of CO$_2$-emissions and fuel consumption per km at defined penetration rates for the VERSIT-classes ‘EU car’ and ‘EU truck’ (or per euro class vehicle types when the euroFOT speed-time profile can be differentiated for euro classes). This output will be combined with the kilometres travelled in the EU with/without the function, in order to determine the environmental impact in terms of fuel consumption and emission in the EU for the defined penetration rates. The information on kilometres travelled with/without the function that is determined within the traffic efficiency assessment has to be enriched with km travelled per euro class. This is done for a combination of vehicle types that is representative for the EU fleet, where vehicle type is defined as in the data needs below. This combination of vehicle types has to be specified before the model runs are performed.

**Required data for emission models:**

**VERSIT+ (TNO) data needs**

The functions modelled in VERSIT+ will be ACC, SL/CC and FEA (if required data are available). The output of the PELOPS traffic simulator will be used as input for the VERSIT+ emission modelling.

VERSIT+ models “regulated emissions” (CO, NO$_x$, PM$_{10}$, HC, and some other less important ones) as well as CO$_2$, based on a database of driving patterns and associated measured emissions for 3100 light duty vehicles (20000 tests on 200 driving cycles) and 500 heavy duty vehicles.

**Analysis “per vehicle”**

VERSIT+ requires first of all the speed and/or acceleration of equipped and unequipped vehicles, at 1 Hz frequency. These data are used to determine the driving pattern and calculate from that the emissions, using the patterns from the VERSIT+ database. For a
reliable and accurate calculation, more information than just speed and acceleration is needed.

The following data are required:
- Speed-time profile and/or acceleration at 1 Hz frequency.
- Vehicle type (collected once per vehicle):
  - ECE vehicle class (M1…), fuel type, emissions class (= EURO class; or construction date), particulate filters, for vans (ECE vehicle class N1) also kerb weight.
  - For heavy duty vehicles: ECE vehicle class (bus, rigid truck, truck, M2, M3, N2, N3), fuel type, emissions class (= EURO class; or construction date), particulate filters.

The following data are nice to have: That is, availability of these data will improve the calculation, and allow distinguishing between effects of the ITS application and effects of other circumstances (“confounding variables”). If these data are not available, then default values can be used:
- On board equipment: Air-conditioning usage, and other equipment in two main groups: mechanical driven (belt) or electrical driven (battery). Some indications of power usage would be nice, but typically hard to recover.
- After treatment temperature, after treatment load. This can be derived from the driving history (hours/days).
- Gear shift strategy. People tend to shift gear at a particular engine speed. In the case that engine speed and vehicle speed is known, gear shift can be deduced (also for automatic gear). For ITS, this can be quite relevant.
- Cold start. If the vehicle stops for longer than half an hour, the engine can be assumed to be cold again, with an increase in the emissions.
- Tyre pressure.
- Mileage.
- For heavy duty vehicles: kerb weight and payload weight

**Analysis “for the fleet”**
For scaling up the following data are also **required**:
- Number of vehicles of each type (see the “vehicle type” entry above for a specification of the data that are needed; additional information, such as simulation of newer technology such as diesel particulate filters.
- Mileage per euro class type (km per year).

**To be done**
It is necessary to translate vehicle km driver at the EU level (or EU region level) per euro class into VERSIT+ classes that represent the EU fleet. It is not likely that all euro class types will be represented in the euroFOT data. The euroFOT data will have to be matched with VERSIT+ classes that represent the EU fleet. Probably, the euroFOT speed-time profiles of the cars will be used for a VERSIT+ class representing EU cars and vans, and the euroFOT data of trucks will be used for a VERSIT+ class representing EU trucks.

**6.4 Indirect environmental effects**
Indirect traffic and therefore also environmental effects are the changes in amount of accident related congestion, based on changes in number of accidents. If accidents are prevented, this means a certain amount of accident related congestion is also avoided. The approach for calculating indirect traffic effects is described in section 5.4. This approach can be applied to all functions. The safety impact assessment produces outputs in terms of changes in accidents at the EU level. By means of a spread sheet that was developed in the
eIMPACT project for safety impacts, the impact of functions on accident related congestion is calculated. The eIMPACT project does not provide separate emissions for congestion.
7 Scaling up and Cost-benefit analysis

7.1 Need for socio-economic assessment & general methodology

Cost-benefit analysis is the most prominent economic assessment tool to prove the profitability of a measure on societal level. In-vehicle safety functions which are tested in euroFOT are sort of “mixed goods” in having private and public elements. Clearly, the car driver and his / her passengers will benefit from using safety functions by improving the driver’s control of the car and the driving situations. Thus, in-vehicle safety functions will reduce the occurrence of dangerous situations and possible collisions from which simultaneously other car drivers and pedestrians will benefit as well. Besides private benefits also public benefits arise which cannot be completely attributed to individual road-users. Regarding public benefits of safety functions supply and demand is insufficient since vehicle buying decisions are only driven by individual rationale.

Following economic reasoning, supporting activities such as standards, informational measures, or obligatory implementation may be justified as means of increasing market penetration of in-vehicle safety functions. Thus, it has to be proven whether society’s welfare will increase when market penetration of these functions is increased. In this respect, CBA can be used in order to proof profitability of the euroFOT from a society’s point of view.

Cost-benefit ratios can be derived from comparing the potential costs of particular euroFOT functions with potential benefits (e.g. accident and time cost savings for users, other traffic participants and the general public). If benefits exceed costs (benefit-cost ratio is above 1) then the function is profitable from the society point of view. Finally an outlook for realistic possible penetration rates will be given. The cost-benefit analysis will be based on the results of WP6400. The impact of each evaluated function in terms of safety benefit, traffic efficiency and environmental impact will be transferred into monetary benefits for the society by applying up-to-date and common cost-unit-rates. This requires a framework whose basic parameters comprises the socio-economic perspective on road safety in general, and allows forecasting potential effects as a consequence of safety technology in particular. Therefore, methodical knowledge of the European project eIMPACT and further published methods from traffic safety and traffic economics researcher were screened and adapted for euroFOT cost-benefit assessment. The benefits will be calculated in general and under different penetration rate scenarios, since depending on the share of newly registered vehicles within the EU-27 fleet, the European traffic function is more or less affected by the impacts of the functions. This is taken into account by using vehicle mileage forecasts to scale up to potential EU-wide benefits depending on the fleet penetration rate.

Additionally, the cost analysis of each selected FOT function considers main influences of function costs like penetration rate and package offers to determine component based estimations for evolved future markets of these functions. Cost-benefit study will allow for each single function to analyse the overall profitability as well as to form rankings and highlight risks and synergy potentials of the functions assessed in WP6500.

7.2 Data needs & impact appraisal

All impacts resulting from WP6400 impact assessment are derived either from direct analysis and evaluation of experimental results and hence, the impact results are gained based on the driven mileage within the test or are linked to a limited fraction of traffic and accident data which are needed to extrapolate e. g. to determine impacts on real-world accidents based on changes in critical FOT events. But for cost-benefit analysis as a support for European policy making, a wider perspective as well as a high level of aggregation is necessary to allow an
assessment of the overall impact from a society’s point of view based on the information gathered in euroFOT.

The general data input from WP6400 is defined by a minimum set of data which is necessary to conduct an overall CBA and must therefore also be considered as crucial input for up-scaling (see Figure 25). Following the general structure of impact assessment process in WP6400, the impacts leading to cost-benefit analysis can be summed up to these different impact types.

- Safety impacts: The reductions of fatalities & injuries are required to be expressed in % of the target accident population, since this format allow to scale up the results of the safety impact assessment, which leads to the conclusion on EU-27 level, which numbers of casualties could be avoided, if all vehicles were equipped with the functions.

- Traffic efficiency impacts: This impact depends on fleet penetration, since network wide benefits in terms of time savings due to harmonised traffic flow only occur when a minimum share of traffic is controlled by the specific function. Micro-simulation of identified market penetration scenarios results in time savings due to higher throughput and less congestion in traffic.

- Fuel efficiency and environmental impacts: Directly measured impacts on fuel consumption because of the use of euroFOT functions need to be quantified per kilometre for different situational variables.

![Figure 25: Overall process of determining socio-economic benefits and costs of IVSS in euroFOT (own figure, based on FESTA handbook)](image-url)
7.3 Scaling up

In the impact assessment chapters 4, 5 and 6, scaling up is described. For efficiency and environment this is done very briefly. In this section the topic of scaling up is described more elaborately. The use of the eIMPACT spread sheet is described in more detail.

Following the impact assessment process depicted in Figure 25, the scaling up needs to integrate the results of all impacts recognised and analysed in euroFOT before scaling up, because the key parameter to predict benefits of IVSS is vehicle mileage driven with the function.

First, a 100-% reference scenario, which scales up the results from evaluating euroFOT test data to the complete EU-27 fleet and hence all vehicle mileage, is needed, afterwards it is possible to determine expectable outcomes by determining to what extent the share of these benefits and costs will be reached due to more or less succeeding fleet and traffic deployment. The central variable used to assess these different scenarios is the forecasted vehicle mileage driven with the function.

Figure 26 shows how the scaling up by vehicle kilometres takes up the results of the preceding assessment steps, segmented by situational variables (SVi). Main outcome is the expectable benefit generated by vehicles consuming fewer resources by substituting vehicles and their mileage provided without the functions in each scenario (Sce.). However, these presumable improvements of the transport function require scaling up of the impacts found in the FOT and supported by hypothesis testing. By comparing benefits and costs – as described above – the efficiency from a societal perspective of the euroFOT functions is quantified based on the FOT findings.

7.3.1 Scaling up safety impacts

Both ABA and EBA will analyse safety impacts (“-x % of fatalities and injuries”) using target population from national accident databases to interpret the impacts related of the hypothesis testing as accurate as possible. This target population takes into account that functions do not necessarily operate under all driving conditions.

In eIMPACT, the collection and compilation of accident data was carried out in close cooperation with the TRACE project and served as a basis for safety impact assessment on
EU-25 level. Data needs followed the approach in the safety impact assessment in eIMPACT which lead to a socio-economic desktop study of functions similar to those in euroFOT. Therefore, these data can be used to scale up the expected accident reduction to EU-27 level by applying the reduction on this set of accident data gathered in the spread sheet and will provide an assumption what impact on accident cost can be expected from the large-scale deployment of the evaluated euroFOT functions. The EU-27 accident numbers are described by three clusters of countries with similar safety performance.

- Cluster 1 (6 countries):
  - Denmark, Finland, Germany, Sweden, The Netherlands, United Kingdom;
- Cluster 2 (8 countries):
  - Austria, Belgium, France, Ireland, Italy, Luxemburg, Malta, Spain;
- Cluster 3 (11 countries):
  - Cyprus, Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Poland, Portugal, Slovakia, Slovenia, Bulgaria, Romania

Furthermore, the cross-tabulated structure also allows considering differences within the evaluated impacts for different situational variables. The level of accident data disaggregation was determined by the methodology for the safety impact assessment in eIMPACT. Since on a European level, there still is no consistent accident database to cover important information about severe injury accidents which could pass for better accident based impact assessment, this cluster-based approach is used to estimate the overall accident avoidance potential for the CBA. Table 24 shows the level of detail available in accident data for scaling up the identified safety impact.
Table 24: Number of accidents, fatalities, injuries for EU-25 (2005) – distribution by situational variables [22]

<table>
<thead>
<tr>
<th></th>
<th>Injury accidents</th>
<th>Fatalities</th>
<th>Seriously injured</th>
<th>Slightly injured</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Totals</strong></td>
<td>1,127,057</td>
<td>36,069</td>
<td>282,128</td>
<td>1,206,847</td>
</tr>
<tr>
<td><strong>Collision type</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collision on the road with pedestrian</td>
<td>11%</td>
<td>13%</td>
<td>13%</td>
<td>8%</td>
</tr>
<tr>
<td>Collision on the road with all other obstacles</td>
<td>6%</td>
<td>7%</td>
<td>6%</td>
<td>6%</td>
</tr>
<tr>
<td>Collision besides the road with pedestrian or obstacle or other single vehicle accidents</td>
<td>13%</td>
<td>22%</td>
<td>16%</td>
<td>11%</td>
</tr>
<tr>
<td>Frontal collision</td>
<td>8%</td>
<td>18%</td>
<td>14%</td>
<td>9%</td>
</tr>
<tr>
<td>Side-by-side collision</td>
<td>5%</td>
<td>2%</td>
<td>3%</td>
<td>5%</td>
</tr>
<tr>
<td>Angle collision</td>
<td>25%</td>
<td>15%</td>
<td>22%</td>
<td>26%</td>
</tr>
<tr>
<td>Rear collision</td>
<td>13%</td>
<td>5%</td>
<td>6%</td>
<td>14%</td>
</tr>
<tr>
<td>Other accidents with two vehicles</td>
<td>6%</td>
<td>3%</td>
<td>4%</td>
<td>6%</td>
</tr>
<tr>
<td>All other collisions</td>
<td>13%</td>
<td>14%</td>
<td>15%</td>
<td>14%</td>
</tr>
<tr>
<td><strong>Road type</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban roads (no motorway)</td>
<td>66%</td>
<td>32%</td>
<td>51%</td>
<td>64%</td>
</tr>
<tr>
<td>Motorway</td>
<td>5%</td>
<td>7%</td>
<td>6%</td>
<td>5%</td>
</tr>
<tr>
<td>Rural roads (no motorway)</td>
<td>29%</td>
<td>61%</td>
<td>43%</td>
<td>30%</td>
</tr>
<tr>
<td><strong>Weather</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adverse</td>
<td>13%</td>
<td>13%</td>
<td>13%</td>
<td>14%</td>
</tr>
<tr>
<td>Normal</td>
<td>87%</td>
<td>87%</td>
<td>87%</td>
<td>86%</td>
</tr>
<tr>
<td><strong>Light conditions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Darkness</td>
<td>26%</td>
<td>39%</td>
<td>30%</td>
<td>26%</td>
</tr>
<tr>
<td>Daylight or twilight or unknown</td>
<td>74%</td>
<td>61%</td>
<td>70%</td>
<td>74%</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At intersection</td>
<td>50%</td>
<td>23%</td>
<td>38%</td>
<td>52%</td>
</tr>
<tr>
<td>No intersection</td>
<td>50%</td>
<td>77%</td>
<td>62%</td>
<td>48%</td>
</tr>
</tbody>
</table>

However, regarding the extent to which this data spreadsheet is up-to-date, some update and maintenance actions need to be taken to use this accident structure for euroFOT impact assessment and later CBA.

- **Up-to-date & consistency:** since the cross-tabulated, multi-variable perspective of this spreadsheet is unique for EU level; the appropriateness of the spreadsheet for the current accident situation is checked by analysing single variables. This applies for type of vehicles involved in accidents, the distribution of casualties over accident types, weather conditions and road types. Especially yearly national accident statistics in cluster 1 countries allow this kind of consistency check.

- **Time series analysis:** the European Commission aims at lowering the number of fatalities from road accidents by further 40% by taking action in all effective fields of road safety policy. That means, cluster specific accident trends for an optimistic and pessimistic reduction of fatalities need to be generated to display these developments.

- **In-depth information & range of WP6400 findings:** ongoing and current research from other projects like accidentology e.g. in ASSESS needs to be regarded. Since this research might also include the distribution of fatalities and injuries over impact speeds and offers more detailed analysis of different crash configurations and their frequencies, this could be used in sensitivity analysis to exploit the information depth gathered in the FOT as accurately as possible.
The methodology of eIMPACT – roughly described - derives the safety benefits for CBA of the safety functions based on expert opinions and desktop studies in an integrated impact assessment. First, the safety impact for 100 % vehicle fleet equipment are determined and applied on forecasted accident numbers, and then the realistic share of potentially effects is determined by quantifying the traffic deployment in terms of mileage driven with the function for different market scenarios. This process is embodied in the data structure of the spreadsheet which allows covering all three dimensions of scaling up – for EU, future states and market scenarios - in the updated spreadsheet. The generated scaled up numbers might as well be modified to test sensitivity of the results.

In the end, the obtained scaled up safety results are based on quite a number of assumptions. For example, no country from cluster 3 is involved in euroFOT, so it can only be assumed that the effects of the functions on driver behaviour and safety are the same as in other countries even though there are different (driving) cultures, acceptance levels, infrastructure (some of the functions might even be (partly) not available for the road network, e.g. when lane markings are missing), etc.

7.3.2 Scaling up efficiency & environmental impacts

After (traffic efficiency and environmental) simulation results are analysed, differences in travel times, fuel consumption and CO₂ emissions between different scenarios are available on a small scale. These simulation results have to be translated to real world impacts by scaling up from the simulated (local) network to the whole of Europe, and from a simulated time frame (for example one peak hour) to a full year. These real world impacts are input for a cost benefit analysis.

Experimental conditions do not necessarily match with, or completely cover, the real world situation. A number of steps are possible to scale up for these conditions: higher penetration rate, time scale (times of the day) and geographical scale, different time periods (for example future demands instead of present demands), weather conditions, lightning conditions and road types, integration of other measures or functions, etcetera. Some of these aspects are taken into account in the scenarios that are used in simulation, for example penetration rate. Others have to be taken into account in scaling up.

There are two main methods to carry out scaling up: a modelling method (with the use of a macro simulation model) and a direct method (with the use of statistics).

The **modelling method** works as follows, in short. The results from micro-simulation (road capacities) form the input for a macro simulation model. A macro simulation model is able to process large scale networks, such as countries. Therefore, in principle the macro simulation results are the scaled up results. However, sometimes there is some more scaling up work needed, for example if the macro simulation model only models a large region (this can be due to budget reasons). In this case the direct scaling up method (see below) can be used additional to the modelling method. Scaling up via macro simulation is not straightforward and it is not widely used. There are some major steps to be taken and questions to be answered before it will be a generally accepted method.

The **direct method** works as follows. Data on mileage and situational variables (road type, traffic situation, etc.) are collected at the EU level. Simulation results are also split for these situational variables. For example, the travel times (for scenarios with 100% penetration and 0% penetration) are calculated for free flow situations on urban roads, rural roads and motorways, and for high density situations on urban roads, rural roads and motorways. So in total the travel times are calculated for six categories, for two scenarios (0% and 100% penetration). From the simulation also the number of kilometres driven in the six categories for the two scenarios is available.

Now the scaling up can take place; in fact this is a (weighted) multiplication of simulation results to the whole EU. For each of the six categories defined by the situational variables...
and for the two scenarios we know in the simulation how many kilometres were driven and what the travel times are. Also for the whole EU we know for each category how many kilometres are driven (per year). A weighted multiplication will then give travel times at the EU level for the two scenarios, and a comparison of travel times can be made between the scenario with no penetration and the scenario with full penetration.

How extensive the direct method is depends on the amount of data that can be found at the EU level and/or the possible estimations that can be made, as well as on the situational variables that are taken into account in the simulation. And this last ‘limitation’ depends on the data that are collected in the FOT.

7.4 Conclusion: Minimum set of data

In summary, for scaling up of euroFOT results leading to CBA, all mentioned concerns needed for a consistent CBA have to be regarded when defining the up scaling to the EU-27 level, the way of forecasting benefits and costs in different market scenario and in general conduct CBA based on the heterogeneous empirical data sources and analysis methods used in euroFOT. The detailed methodology will be described in D6.7 “Cost-Benefit Study”.

- Vehicle mileage for situational variables: the best way to estimate benefits related to changes within the transport function is to quantify the share of mileage affected by the tested functions. Hence, all impacts need to be linked to a proportion of mileage for each relevant, defined and testable situational variable.

- Safety impact in terms of injury reduction: the difficulties of showing safety improvements based on non-crash conflicts has been brought up. However, if the harmonised results of hypothesis testing with EBA and ABA allow the conclusion that accidents may be avoided by a function, it is crucial – and therefore part of the minimum set of data – to express this avoidance potential in terms of reduction of fatalities and injuries.

- Sensitivity results based on range and distribution of potential impacts and basic parameters: main outcome of CBA is determining whether or not it is efficient from the public perspective to implement the expected changes and resulting impacts by investing cost necessary to achieve them. Hence, all assumptions (e. g. accident forecast) made in the process that may affect the BCR and impair certainty of the assessment need to be the subject of sensitivity analysis, since stochastic simulation for all parameters (e. g. oscillation of future discount rates) which would deliver more detailed insights for the results, is not feasible due to lack of empirical evidence for probability distributions needed for such analysis [45].
8 Discussion

In this document several topics have been mentioned which pose difficulties and challenges for the impact assessment team. This chapter discusses those topics (challenges and solutions) and describes the consequences for the work carried out and the results of the impact assessment.

The topics for discussion are:

- Safety impact assessment
- Scaling up
- Data quality
- Integration of results
- Debundling
- Timing and deadlines

8.1 Challenges and solutions

In this section the challenges and solutions are described per topic.

Safety impact assessment

In the safety impact assessment there are a number of concerns / challenges. These are already mentioned in chapter 4. A major issue in the safety impact assessment is the relationship between driver behaviour and accidents, fatalities and injuries. Traffic safety is expressed in terms of the number of fatalities and injuries and sometimes physical / material damage. However, in an FOT (where a limited number of vehicles drives around for a limited amount of time) probably no accidents happen (or few); at least not enough to be able to make a sound statement on traffic safety. For this reason, a link between driver behaviour and number of fatalities and injuries needs to be established, using FOT data (so-called crash predictors).

The relationship between changes in the evaluated crash predictors, when comparing baseline and treatment, and accident involvement is not straightforward. Ideally, one would select and compare only events and/or aggregate measures which are known to be predictive of actual crash involvement. If this relationship is established, an experimentally identified reduction in the treatment phase could then be used to directly predict a reduction in future crash involvement. Unfortunately, such relationships are yet not fully established, at least not for FOT data.

So, insight into crash causation mechanisms is the key both to the selection of relevant measures of change between baseline and treatment, as well as for interpretation of what those changes mean, in terms of how the target crash population may change if the evaluated ADAS is introduced on a larger scale in the vehicle fleet.

In euroFOT, three safety impact analysis methods are used: Events Based Analysis (EBA), Aggregation Based Analysis (ABA) and Physical Risk Modelling (PRM). Depending on the function being analysed and the hypotheses to be answered, one of these methods is chosen. EBA and ABA are based on literature and applied in earlier studies. PRM is a simulation based approach. All methods work with FOT data. EBA, ABA and PRM are complementary forms of analysis which explore the impact of ADAS from different angles, based on how the ADAS safety impact is conceptualized in terms of influence on crash causation.
The adaptations of these methods to the euroFOT project and the flexibility and different insights the use of three methods offers, enable euroFOT to use the most up-to-date methodologies there are available at the moment, and to make another step in the topic of crash causation.

Scaling up
In euroFOT a direct method for scaling up will be used. For this direct method data on mileage and all situational variables (road type, traffic situation, weather, etc.) have to be collected at the EU level. A challenge here is to find all data that are needed, and to be sure the data are reliable.

Because of the reliability and availability of the data to be used, euroFOT has limited the scaling up to data on mileage for the situational variables road type and traffic situation. This means that other situational variables such as weather, lighting, road curvature and number of lanes are not taken into account. Only for safety some more data may be used that are available from the eIMPACT project. This limitation of the data to be used means that there is less sophistication in the scaling up. On the other hand, there is no point in using data that are not trustworthy. On road type and traffic situation data can be found at the EU level. (Parts of) these data can be found in different sources, so that a comparison can be made between those sources. For road type three levels will be used: motorways, rural roads and urban roads. For traffic situation two levels will be used: congestion and free flow. The steps made in scaling up in finding data on mileage, road type and traffic situation can be seen as a step towards a more sophisticated and extensive scaling up.

Data quality
For some functions in the study there are limitations in the data that will be measured, logged and provided:

- SafeHMI: the activation status and settings of the function are not logged. This means that the route advice that is given is not available so there is no information on whether the driver has followed the advice.
- FEA: the data that are measured are the location of the vehicle and the fuel consumption, every thirty minutes. These are very rough data; for example routes and accelerations are not measured.
- LDW (Italian VMC): only subjective data will be collected for LDW, coming from questionnaires and interviews. No objective data are measured
- CSW: objective as well as subjective data are collected. The function is installed in two vehicles and the duration of the experiment is limited to a few days. Therefore only a few trips are collected for each driver. Due to limited time only one questionnaire (time 4) is provided to the drivers after the experiment.

The challenge is to say something meaningful about the functions. In some situations the objective data will hardly be used to assess the functions, since the right indicators are not there; the assessment will then rely on the subjective data. The extent to which this will be the case will become clear when the FOT has finished and data analysis has taken place.

Integration of results
The integration of results is already mentioned to some extent in section 2.5. Every VMC has its own measurement functions and measures in its own way, and every test site has its own characteristics. This makes the integration of results for one function over the different test sites not straightforward. When comparisons are made, it is difficult to say how possible
differences arise; is there a difference in driving style (driver behaviour) between countries, a difference between the functions tested or a difference caused by a variation in measurement functions?

To (partly) make up for these uncertainties, for functions that are tested on more than one test site there is a common list of performance indicators so that the VMCs measure the same performance indicators and also in a uniform way. For the situational variables there is also one common list, but not all situational variables are measured at each test site.

Besides this uniformity in performance indicators and situational variables what contributes to the integration of results is a good and clear overview of the results and mentioning of differences between test sites when giving the integrated results.

**Debundling**

In euroFOT, some vehicles drive around with one function, others have multiple functions on board. In the impact assessments of the functions the results have to be split as much as possible. However, there are two challenges. The impact challenge refers to the risk that, with bundled functions, it might not be possible to tell the two functions apart in terms of which safety (or other) impact they have. The interaction challenge refers to a different type of worry, which is that the impact of one function might be enhanced or negated when another function is also present in the vehicle.

For the impact challenge, two things are needed, namely separation of crash contributing factors and knowledge of the underlying causation mechanisms for the targeted crash type. In section 2.6, examples and research are given how to handle this issue. In the interaction challenge, relevant interactions between functions are identified, and the euroFOT task force arrived at one type of interaction that seemed worthwhile and empirically possible to investigate further. This interaction is the change in lateral control as a function of ACC usage.

One finding of the task force is that in the deployed bundles, the issue of two functions addressing exactly the same contributing factor does not seem to arise. Instead, the functions in the euroFOT can be impact bundled based on the crash type they intend to address, and in relation to that crash type can be arranged in a sequential order.

**Timing and deadlines**

Impact assessment is carried out at the end of the project, after the FOT is conducted and data analysis is performed. This means that delay in the FOT or data analysis automatically means delay in the impact assessment.

To make sure that delay earlier in the project does not affect the impact assessment too much, hypotheses are prioritized. In this way the impact assessment will in any case evaluate the most important hypotheses; these are the hypotheses that are essential for the evaluation. The ‘nice to have’ hypotheses can – if necessary – be left out of the evaluation.

**8.2 Consequences for results**

The challenges and their solutions mentioned in the previous section have some consequences for the results of the impact assessment. This mainly has to do with the extent to which the impact assessment will be carried out, the level of detail and the comparability between test sites.

- Safety impact assessment: there are still knowledge gaps in how to carry out a safety impact assessment. EuroFOT uses the best methodologies available. However, the
relationship between driver behaviour (crash causation indicators) and fatalities and injuries is still hard to establish.

- Scaling up: for scaling up a lot of data need to be found and used. If not all data needed can be found, some estimations need to be made, or the data need to be collected on a higher level (for example not per country but for the whole EU or regions in the EU). It is also possible that the scaled up results will be given with some margins.

- Data quality: the limitations of the data for SafeHMI, FEA and CSW means that the impact assessment will not be very extensive. The worst case scenario is that only subjective data will be analysed for these functions.

- Integration of results: when a lot of differences arise between the measurement functions and data of the different test sites, it will be difficult to make a good comparison between test sites and to give one result for a function that holds for the different test sites. An overall result (that can be used in the cost benefit analysis) will be given. However, if there are too many differences, the results will possibly also be given for a range, or separately for the test sites. Integrated results will be given with some information about (possible causes for) differences between test sites.

- Debundling: for some hypotheses in Annex 2A, the unit of analysis will not be a single function, but rather a combination of two or more functions. Where it is decided that the effect of a function cannot be disentangled from the effect of another function, this will be highlighted in the final report, along with the implications of this for the interpretation of the data deriving from the hypothesis testing process.

- Timing and deadlines: the more delay there is in the conduction of the FOT and data analysis, the less detailed and extensive the impact assessment will be. The worst case scenario is that only the top hypotheses will be tested.
9 References

http://www.its.leeds.ac.uk/festa/,  


[26] Traffic efficiency Impact Assessment Plan v1.0, F. Faber, E. Jonkers, F. Christen, M. Benmimoun, February 2010


[28] Ljung Aust, M., Regan, M., & Benmimoun, M (2011), “Disentangling the effects of advanced driver assistance system functions in field operational tests: recommendations from the european “eurofot” project”, ITS Lyon, 6-9 June

Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment


Annex 1  Glossary

In this Annex the reader will find a selection of words coming from the official euroFOT glossary which is particularly important for the understanding of this deliverable.

The euroFOT glossary started inside euroFOT SP2 and is based on the FESTA glossary. Every time the glossary is updated, the parallel European supporting initiative FOT-NET\(^1\) is notified; the glossary is then updated on the FOT-NET website and other FOT projects such as Tele-FOT are notified of the new available version of this glossary. For this reason we invite the readers of this report to also consult the euroFOT glossary on [http://www.fot-net.eu/](http://www.fot-net.eu/).

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FOT aka Field Operational Test</strong></td>
<td>A study undertaken to evaluate a function, or functions, under normal operating conditions in environments typically encountered by the host vehicle(s) using quasi-experimental methods.</td>
</tr>
<tr>
<td><strong>Function</strong></td>
<td>A combination of hardware and software enabling one or more functions.</td>
</tr>
<tr>
<td><strong>System</strong></td>
<td>Implementation of a set of rules to achieve a specified goal.</td>
</tr>
<tr>
<td><strong>Use case</strong></td>
<td>A specific event in which a system is expected to behave according to a specified function.</td>
</tr>
<tr>
<td><strong>Situation</strong></td>
<td>One specific level or a combination of more specific levels of situational variables.</td>
</tr>
<tr>
<td><strong>Situational variable</strong></td>
<td>An aspect of the surroundings made up of distinguishable levels. At any point in time at least one of these levels must be valid.</td>
</tr>
<tr>
<td><strong>System state</strong></td>
<td>The current setting of a system.</td>
</tr>
<tr>
<td><strong>Scenario</strong></td>
<td>A use case in a specific situation.</td>
</tr>
<tr>
<td><strong>Research question</strong></td>
<td>General question to be answered by compiling and testing related specific hypotheses.</td>
</tr>
<tr>
<td><strong>Hypothesis</strong></td>
<td>A specific statement linking a cause to an effect and based on a mechanism linking the two. It is applied to one or more functions and can be tested with statistical means by analysing specific performance indicators in specific scenarios. A hypothesis is expected to predict the direction of the expected change.</td>
</tr>
<tr>
<td><strong>Baseline period/phase</strong></td>
<td>The part of the data collection during which the function(s) operate in &quot;silent mode&quot;, that is, they collect data, but do not give any signals to the driver. From the viewpoint of the driver the function(s) is/are off.</td>
</tr>
<tr>
<td><strong>Treatment period/phase</strong></td>
<td>The part of the data collection during which the function(s) are switched on by the experimental leader, such that they are either active all the time, or can be switched on or off by the driver.</td>
</tr>
<tr>
<td><strong>Baseline within comparison situation</strong></td>
<td>Scenario with system under evaluation &quot;turned off&quot;</td>
</tr>
<tr>
<td><strong>Treatment within comparison situation</strong></td>
<td>Scenario with system under evaluation &quot;turned on&quot;</td>
</tr>
<tr>
<td><strong>Controlled factors</strong></td>
<td>Are those factors that are kept constant within one analysis. The data are filtered such that only occurrences in which the controlled factors assume the intended values are selected.</td>
</tr>
</tbody>
</table>
### Variable factors
Are covariates, they are not kept constant within one analysis, but their values are logged and their influence on the results is considered.

### Performance indicator
Quantitative or qualitative indicator, derived from one or several measures, agreed on beforehand, expressed as a percentage, index, rate or other value, which is monitored at regular or irregular intervals and can be compared to one or more criteria.

1 – FOT-NET: the FOT-Net project aims to create a networking platform for anyone interested in Field Operational Tests, their set-up and their results. More information on this project can be found at [http://www.fot-net.eu/](http://www.fot-net.eu/)
Annex 2  Hypotheses List and Worked Examples of Hypotheses Testing

This Annex contains a list with hypotheses and examples of hypotheses testing. The list with hypotheses is divided in four, following the four different impact areas. The structure of this Annex is as follows:

- **Annex 2A**: Hypotheses List
  - 2A.1: Hypothesis for Behavioural impact assessment
  - 2A.2: Hypothesis for Safety impact assessment
  - 2A.3: Hypothesis for Traffic Efficiency impact assessment
  - 2A.4: Hypothesis for Environmental impact assessment

- **Annex 2B**: Hypotheses Testing for Objective FOT Data – Worked Examples
- **Annex 2C**: Hypotheses Testing for Subjective FOT Data – Worked Examples

Note that the hypotheses in Annex 2A show only a partial overlap with the list of hypotheses that can be found in euroFOT Deliverable 2.1 [49]. This is because in deliverable 2.1, a very large set of tentative hypothesis was identified, pointing to various interesting areas of potential investigation. Since then, the hypotheses have been iteratively refined and reduced in number over the course of the project to make the list suitable for data analysis. This refinement involved several processes: prioritising hypotheses, simplifying hypotheses, reducing the ambiguity of hypotheses, reducing overlap between hypotheses, eliminating hypotheses that could not be tested for technical or other reasons, and considering whether the hypothesis in question relates to a single function or bundle of functions. Note also that the list in Annex 2A represents the current status of that iterative work, i.e. it is not conclusive. Further modifications may take place before the project finishes.

2A.1: Hypothesis under consideration for testing of user related aspects by means of questionnaire data

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>HYPOTHESIS</th>
<th>CLASSIFICATION</th>
<th>PERFORMANCE INDICATOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCW</td>
<td>7</td>
<td>Using FCW, focus and level of engagement on secondary tasks will increase.</td>
<td>Driver Behaviour</td>
</tr>
<tr>
<td>FCW</td>
<td>9</td>
<td>The acceptance of FCW will be positive.</td>
<td>Acceptance</td>
</tr>
<tr>
<td>FCW</td>
<td>10</td>
<td>Sensation seeker drivers will perceive the warnings from FCW as annoying.</td>
<td>Acceptance</td>
</tr>
<tr>
<td>FCW</td>
<td>11</td>
<td>Certain features of the functions, in terms of usability, influence acceptance.</td>
<td>Acceptance</td>
</tr>
<tr>
<td>FCW</td>
<td>12</td>
<td>Certain features of the functions, in terms of usefulness, influence user acceptance?</td>
<td>Acceptance</td>
</tr>
<tr>
<td>FCW</td>
<td>13</td>
<td>Acceptance changes over time with function use.</td>
<td>Acceptance</td>
</tr>
<tr>
<td>FCW</td>
<td>14</td>
<td>Trust in function changes over time with function use.</td>
<td>Trust</td>
</tr>
<tr>
<td>FCW</td>
<td>16</td>
<td>Driver workload decreases over time with function use.</td>
<td>Workload</td>
</tr>
<tr>
<td>FCW</td>
<td>17</td>
<td>User practices (heuristics, rules) will change over time during the FOT</td>
<td>User Practices</td>
</tr>
<tr>
<td>FCW</td>
<td>18</td>
<td>Drivers will not abuse or misuse FCW</td>
<td>Abuse/Misuse</td>
</tr>
<tr>
<td>No.</td>
<td>Description</td>
<td>Table/Measurement</td>
<td>Unit(s)</td>
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</tr>
<tr>
<td>12</td>
<td>Using ACC, focus and level of engagement on secondary tasks will increase.</td>
<td>Driver Behaviour</td>
<td>Self-reported level of engagement on secondary tasks.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>xxx_mis_1b_4</td>
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<tr>
<td>15</td>
<td>ACC increases driving perceived safety and comfort.</td>
<td>Acceptance</td>
<td>Self-reported rating of increase in safety</td>
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<tr>
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<td></td>
<td>Self-reported rating of degree of change in comfort</td>
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<td>xxx_sys_1h_4</td>
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<td>xxx_use_2d_4</td>
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<td>Certain features of the functions, in terms of usability, influence acceptance.</td>
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<td>Self-reported ratings of ease of function use</td>
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<td></td>
<td></td>
<td></td>
<td>Items under xxx_eas_1_4</td>
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<td>Self-reported ratings of acceptance</td>
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<td>Items under Eas_a_4</td>
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<td>Certain features of the functions, in terms of usefulness, influence user acceptance?</td>
<td>Acceptance</td>
<td>Self-reported ratings of usefulness of function</td>
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<td>Self-reported ratings of acceptance</td>
</tr>
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<td></td>
<td></td>
<td>Items under use_1_4</td>
</tr>
<tr>
<td>18</td>
<td>Acceptance changes over time with function use.</td>
<td>Acceptance</td>
<td>Self-reported ratings of acceptance</td>
</tr>
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<td></td>
<td></td>
<td>Items under xxx_ac_1_2</td>
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<td>Trust</td>
<td>Self-reported ratings of trust</td>
</tr>
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<td>Items under xxx_ac_1_2</td>
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<td>Workload</td>
<td>Self-reported ratings of workload</td>
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<td>Items under xxx_mw_1_3</td>
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<td>Self-reported user practices</td>
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<td></td>
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<td>xxx_upr_1b_4</td>
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<td>Abuse/Misuse</td>
<td>Self-reported misuse and abuse</td>
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<td>Items under</td>
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<td>SL experience</td>
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<td>7</td>
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<td>Using SL will increase comfort and pleasure to drive</td>
<td>Acceptance</td>
<td>Self-reported ratings of degree of change in comfort and enjoyment xxx_sys_1h_4 xxx_sys_1i_4</td>
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<tr>
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<td>SL experience</td>
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<td>17a</td>
<td>CC experience</td>
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<td>The level of CC acceptance will increase with CC experience</td>
<td>Acceptance</td>
<td>Self-reported rating of acceptance Items under xxx_ac_1_2 xxx_ac_1_3 xxx_ac_1_4</td>
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<tr>
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<td>CC experience</td>
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<td>Using CC will increase comfort and pleasure to drive</td>
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<td>Certain features of the functions, in terms of usability, influence acceptance.</td>
<td>Acceptance</td>
<td>Self-reported ratings of ease of function use Items under xxx_eas_1_4</td>
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<td>SL experience</td>
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<td>30</td>
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<td>Certain features of the functions, in terms of usefulness, influence user acceptance?</td>
<td>Acceptance</td>
<td>Self-reported ratings of usefulness of functions</td>
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<td>SL experience</td>
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<td>31</td>
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<td>Acceptance changes over time with function use.</td>
<td>Acceptance</td>
<td>Self-reported ratings of acceptance Items under use_1_4</td>
</tr>
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<td>32</td>
<td>SL experience</td>
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<td></td>
<td>Trust in function changes over time with function use.</td>
<td>Trust</td>
<td>Self-reported ratings of trust Items under xxx_ac_1_2 xxx_ac_1_3 xxx_ac_1_4</td>
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<td>SL experience</td>
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<td>34</td>
<td>SL experience</td>
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<tr>
<td></td>
<td>Driver workload decreases over time with function use.</td>
<td>Workload</td>
<td>Self-reported ratings of workload Items under xxx_mw_1_3 xxx_mw_1_4</td>
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<td>SL experience</td>
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<tr>
<td>35</td>
<td>SL experience</td>
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<td></td>
<td>User practices (heuristics, rules) will change over time during the FOT</td>
<td>User Practices</td>
<td>Self-reported user practices Items xxx_upr_1a_4 xxx_upr_1b_4</td>
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<tr>
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<td>SL experience</td>
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</tr>
<tr>
<td>36</td>
<td>SL experience</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Drivers will not abuse or misuse SL/CC</td>
<td>Abuse/Misuse</td>
<td>Self-reported misuse and abuse Items under Mis_1_4</td>
</tr>
<tr>
<td>LDW</td>
<td>1</td>
<td>Users perceived that LDW decreases/mitigates lateral incidents, near-crashes, and accidents</td>
<td>Safety</td>
</tr>
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<td>-------</td>
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<td>---------------------------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>LDW</td>
<td>2</td>
<td>Users perceived that LDW influences lateral driving performance.</td>
<td>Safety</td>
</tr>
<tr>
<td>LDW</td>
<td>12</td>
<td>Users perceived that LDW increases the use of turn indicators.</td>
<td>Driving behaviour, Safety</td>
</tr>
<tr>
<td>LDW</td>
<td>13</td>
<td>Users perceived that LDW increases usage over time.</td>
<td>Usage, Safety</td>
</tr>
<tr>
<td>LDW</td>
<td>14</td>
<td>Users perceived that LDW increases night driving.</td>
<td>Usage</td>
</tr>
<tr>
<td>LDW</td>
<td>15</td>
<td>Users perceived that LDW warning leads to an appropriate driver reaction.</td>
<td>Usage, Safety</td>
</tr>
<tr>
<td>LDW</td>
<td>16</td>
<td>LDW is well accepted by the driver.</td>
<td>Acceptance</td>
</tr>
<tr>
<td>LDW</td>
<td>17</td>
<td>LDW acceptance/adoption increases with LDW usage.</td>
<td>Acceptance</td>
</tr>
<tr>
<td>LDW</td>
<td>18</td>
<td>Certain features of the functions, in terms of usability, influence acceptance.</td>
<td>Acceptance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>LDW</td>
<td>19</td>
<td>Certain features of the functions, in terms of usefulness, influence user acceptance?</td>
<td>Acceptance</td>
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<tr>
<td>LDW</td>
<td>20</td>
<td>Acceptance changes over time with function use.</td>
<td>Acceptance</td>
</tr>
<tr>
<td>LDW</td>
<td>21</td>
<td>Trust in function changes over time with function use.</td>
<td>Trust</td>
</tr>
</tbody>
</table>

Deliverable D6.2 Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment
<table>
<thead>
<tr>
<th>LDW</th>
<th>22</th>
<th>Driver workload decreases over time with function use.</th>
<th>Workload</th>
<th>Self-reported ratings of workload items under xxx_mw_1_3 xxx_mw_1_4</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDW</td>
<td>23</td>
<td>User practices (heuristics, rules) will change over time during the FOT</td>
<td>User Practices</td>
<td>Self-reported user practices items xxx_upr_1a_4 xxx_upr_1b_4</td>
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<tr>
<td>LDW</td>
<td></td>
<td>Level of perceived safety of LDW increases over time, compared to the expectation that drivers expressed at buying.</td>
<td>Trust</td>
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<tr>
<td>LDW</td>
<td></td>
<td>Drivers believe that LDW influences positively their driving behaviour (with respect to specific use cases, i.e. lane change).</td>
<td>Driver behaviour</td>
<td></td>
</tr>
<tr>
<td>LDW</td>
<td></td>
<td>Perceived ease of use of LDW increases or stabilizes at high levels over time, compared to the expectation that drivers expressed at buying.</td>
<td>Acceptance</td>
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<tr>
<td>LDW</td>
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<td>Drivers believe that LDW warnings are effective and relevant (as regards to specific aspects as system activation or lane departure).</td>
<td>Acceptance</td>
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<td>LDW</td>
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<td>Use of LDW does not increase drivers' workload, also compared to the expectation that drivers expressed at buying.</td>
<td>Workload</td>
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<td>24</td>
<td>Drivers will not abuse or misuse LDW</td>
<td>Abuse/Misuse</td>
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<td>BLIS</td>
<td>4</td>
<td>Function acceptance/adoption will increase with use of BLIS</td>
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<td>Self-reported ratings of usefulness of functions</td>
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<td></td>
<td>Self-reported ratings of acceptance items under Eas_a_4</td>
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Deliverable D6.2
Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment
<p>| | | | |</p>
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<tbody>
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<td>Acceptance changes over time with function use.</td>
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<tr>
<td><strong>BLIS</strong></td>
<td>7b</td>
<td>Trust in function changes over time with function use.</td>
<td>Trust</td>
</tr>
<tr>
<td><strong>BLIS</strong></td>
<td>9</td>
<td>Driver workload decreases over time with function use.</td>
<td>Workload</td>
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<td>User practices (heuristics, rules) will change over time during the FOT</td>
<td>User Practices</td>
</tr>
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<td>Drivers will not abuse or misuse BLISS</td>
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<td>NAV increases perceived driving comfort.</td>
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<td>Acceptance of NAV will increase with experience.</td>
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<td>Trust of NAV will increase with experience.</td>
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<td>Driver workload decreases over time with function use.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>S-HMI</strong></td>
<td>18</td>
<td>User practices (heuristics, rules) will change over time during the FOT</td>
<td>User Practices</td>
</tr>
<tr>
<td><strong>S-HMI</strong></td>
<td>19</td>
<td>Drivers will not abuse or misuse S-HMI</td>
<td>Abuse/Misuse</td>
</tr>
<tr>
<td><strong>CSW</strong></td>
<td>6</td>
<td>Driver consider appropriate the warning (not too early or too late)</td>
<td>Acceptance</td>
</tr>
<tr>
<td><strong>CSW</strong></td>
<td>8</td>
<td>Certain features of the functions, in terms of usability, influence acceptance.</td>
<td>Acceptance</td>
</tr>
<tr>
<td><strong>CSW</strong></td>
<td>9</td>
<td>Certain features of the functions, in terms of usefulness, influence user acceptance?</td>
<td>Acceptance</td>
</tr>
<tr>
<td><strong>CSW</strong></td>
<td>10</td>
<td>Acceptance changes over time with function use.</td>
<td>Acceptance</td>
</tr>
<tr>
<td><strong>CSW</strong></td>
<td>11</td>
<td>Trust in function changes over time with function use.</td>
<td>Trust</td>
</tr>
<tr>
<td><strong>CSW</strong></td>
<td>13</td>
<td>Driver workload decreases over time with function use.</td>
<td>Workload</td>
</tr>
<tr>
<td><strong>CSW</strong></td>
<td>14</td>
<td>User practices (heuristics, rules) will change over time during the FOT</td>
<td>User Practices</td>
</tr>
<tr>
<td><strong>CSW</strong></td>
<td>15</td>
<td>Drivers will not abuse or misuse CSW</td>
<td>Abuse/Misuse</td>
</tr>
<tr>
<td><strong>IW</strong></td>
<td>8</td>
<td>The acceptance of IW will be positive</td>
<td>Acceptance</td>
</tr>
<tr>
<td><strong>IW</strong></td>
<td>9</td>
<td>Function acceptance/adoption will increase with IW usage</td>
<td>Acceptance</td>
</tr>
<tr>
<td><strong>IW</strong></td>
<td>10</td>
<td>Certain features of the functions, in terms of</td>
<td>Acceptance</td>
</tr>
</tbody>
</table>
| IW | 11 | Certain features of the functions, in terms of usefulness, influence user acceptance? | Acceptance | Self-reported ratings of usefulness of functions
 |  |  |  | Self-reported ratings of acceptance Items under Eas_a_4
 | IW | 13 | Trust in function changes over time with function use. | Trust | Self-reported ratings of trust Items under xxx_ac_1_2
 |  |  |  | xxx_ac_1_3
 |  |  |  | xxx_ac_1_4
 | IW | 15 | Driver workload decreases over time with function use. | Workload | Self-reported ratings of workload Items under xxx_mw_1_3
 |  |  |  | xxx_mw_1_4
 | IW | 16 | User practices (heuristics, rules) will change over time during the FOT | User Practices | Self-reported user practices Items xxx_upr_1a_4
 |  |  |  | xxx_upr_1b_4
 | IW | 17 | Drivers will not abuse or misuse IW | Abuse/Misuse | Self-reported misuse and abuse Items under Mis_1_4

Deliverable D6.2
Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment
### 2A.2: Hypothesis under consideration for testing by means of objective data to aid the safety impact calculation

<table>
<thead>
<tr>
<th>Function</th>
<th>Target Crash Population</th>
<th>Hypothesis on what might change in the experimental data when the function is made available to the driver</th>
<th>Type of analysis that can be performed to test the hypothesis on the data collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC+FCW</td>
<td>Rear-end crashes</td>
<td>Using ACC+FCW, the number of forward crashes, near crashes, and incidents will decrease.</td>
<td>EBA analysis of event frequencies (forward accidents and incidents) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ACC+FCW use increases over time</td>
<td>PRM modelling of risk and severity of crash involvement in car following situations with ACC+FCW on and ACC+FCW off</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ACC+FCW decreases average speed.</td>
<td>EBA analysis of event frequencies (forward accidents and incidents) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ACC+FCW decreases the number of critical time gaps to the leading vehicle.</td>
<td>EBA analysis of event frequencies (instances of time headway shorter than X) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ACC+FCW increases average time gap.</td>
<td>ABA analysis of mean time headway with ACC+FCW on compared to ACC+FCW off</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Using FCW+ACC, focus on primary task (time in which the driver looks straight ahead) will decrease over time on motorways.</td>
<td>ABA analysis of visual behaviour measures like percentage road centre, glance frequency, glance duration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Using ACC+FCW, frequency of drowsy driving will increase.</td>
<td>Eye Tracking indicators (glance freq, percent road centre, glance duration, PERCLOS), SDLP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Using ACC+FCW, driver’s reaction time (time to reach the brake pedal) will increase if ACC is used most of the time and decrease if only the FCW function is actually used</td>
<td>EBA analysis from footwell video of Response time when reaching for the brake pedal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The driver changes the use of ACC over time by increasing the occurrence of overriding.</td>
<td>Usage of accelerator pedal when function is active</td>
</tr>
</tbody>
</table>

Deliverable D6.2
Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment
<table>
<thead>
<tr>
<th><strong>LDW</strong></th>
<th><strong>BLIS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crashes initiated by an inadvertent lane departure (single or multi-vehicle)</strong></td>
<td><strong>Lane change crashes</strong></td>
</tr>
<tr>
<td><strong>LDW decreases/mitigates lateral incidents, near-crashes, and accidents.</strong></td>
<td><strong>BLIS decreases the number of crashes, near crashes, incidents</strong></td>
</tr>
<tr>
<td><strong>EBA analysis of event frequencies (lateral accidents and incidents) per mileage/time driven/no of drivers</strong></td>
<td><strong>EBA analysis of event frequencies (lane change accidents and incidents) per mileage/time driven/no of drivers</strong></td>
</tr>
<tr>
<td><strong>LDW influences lateral driving performance.</strong></td>
<td><strong>BLIS reduces use of turn indicator to change lanes</strong></td>
</tr>
<tr>
<td><strong>EBA analysis of event frequencies (number of passing the lane markings) per mileage/time driven/no of drivers</strong></td>
<td><strong>EBA analysis of the frequency of lane change indicator use when on multiline roads in baseline vs. treatment</strong></td>
</tr>
<tr>
<td><strong>LDW increases the use of turn indicators in lane change situations.</strong></td>
<td><strong>PRC history in combination with LDW warnings</strong></td>
</tr>
<tr>
<td><strong>Relation between lane change occurrences (measuring position in lane) and use of turn indicators compared in LDW ON / OFF situations</strong></td>
<td><strong>ABA analysis of visual behaviours related to drowsiness (Eye closure time, eye closure frequency, etc) and vehicle behaviours related to degraded control (Steering wheel entropy, severe corrections, etc), comparing baseline and treatment</strong></td>
</tr>
<tr>
<td><strong>LDW increases usage more and more over time.</strong></td>
<td><strong>ABA analysis of changes in steering wheel angle/velocity/frequency of movement in baseline (no LDW) compared to treatment (LDW available)</strong></td>
</tr>
<tr>
<td><strong>Time series based EBA analysis of LDW activation occurrences (total number of activations per X hours of driving)</strong></td>
<td><strong>Time series based ABA analysis of LDW activation time (total time in use per X hours of driving)</strong></td>
</tr>
<tr>
<td><strong>LDW warning leads to an appropriate driver reaction. Appropriate here defined as a correct evasive manoeuvre (i.e. not turning in the wrong direction).</strong></td>
<td><strong>EBA analysis of driver response in lane relevant lane exceedance situations</strong></td>
</tr>
<tr>
<td><strong>ABA analysis of changes in steering wheel angle/velocity/frequency of movement in baseline (no LDW) compared to treatment (LDW available)</strong></td>
<td><strong>ABA analysis of visual behaviours related to drowsiness (Eye closure time, eye closure frequency, etc) and vehicle behaviours related to degraded control (Steering wheel entropy, severe corrections, etc), comparing baseline and treatment</strong></td>
</tr>
<tr>
<td><strong>LDW decreases drowsy driving</strong></td>
<td><strong>BLIS issues warnings when the driver is not looking at the road ahead</strong></td>
</tr>
<tr>
<td><strong>EBA analysis of driver response in lane relevant lane exceedance situations</strong></td>
<td><strong>PRC history in combination with LDW warnings</strong></td>
</tr>
<tr>
<td><strong>BLIS decreases the number of crashes, near crashes, incidents</strong></td>
<td><strong>EBA analysis of event frequencies (lane change accidents and incidents) per mileage/time driven/no of drivers</strong></td>
</tr>
<tr>
<td><strong>EBA analysis of the frequency of lane change indicator use when on multiline roads in baseline vs. treatment</strong></td>
<td><strong>EBA analysis of event frequencies (number of passing the lane markings) per mileage/time driven/no of drivers</strong></td>
</tr>
</tbody>
</table>
### IW

<table>
<thead>
<tr>
<th>IW</th>
<th>Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>IW decreases the number of crashes, near crashes, incidents</td>
<td>EBA analysis of event frequencies (drowsiness and prolonged distraction related accidents and incidents) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td>IW increases lateral driving performance</td>
<td>EBA analysis of event frequencies (number of passing the lane markings) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td></td>
<td>EBA analysis of event frequencies (exceeding a certain offset to the lane markings) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td></td>
<td>ABA analysis of changes in steering wheel angle/velocity/frequency of movement in baseline (no LDW) compared to treatment (LDW available)</td>
</tr>
<tr>
<td>IW decreases drowsy driving</td>
<td>ABA analysis of visual behaviours related to drowsiness (Eye closure time, eye closure frequency, etc) and vehicle behaviours related to degraded control (Steering wheel entropy, severe corrections, etc), comparing baseline and treatment</td>
</tr>
<tr>
<td>IW increases usage more and more over time</td>
<td>Time series based EBA analysis of IW activation occurrences (total number of activations per X trips in treatment)</td>
</tr>
</tbody>
</table>

### SL/CC

<table>
<thead>
<tr>
<th>SL/CC</th>
<th>Rear-end crashes</th>
<th>Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL/CC</td>
<td>Using SL (resp. CC), the number of forward crashes, near crashes, and incidents will decrease</td>
<td>EBA analysis of event frequencies (forward accidents and incidents) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td></td>
<td>Using SL (resp. CC) reduces speeding occurrences</td>
<td>PRM modelling of risk and severity of crash involvement in car following situations with SL on, CC on, and SL or CC off.</td>
</tr>
<tr>
<td></td>
<td>Using SL (resp. CC) will increase the occurrences of strong jerks</td>
<td>EBA analysis of event frequencies (Instances of jerks larger than X) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td></td>
<td>Using SL (resp. CC), the number of harsh braking/strong decelerations will decrease.</td>
<td>EBA analysis of event frequencies (hard deceleration events) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td></td>
<td>SL (resp. CC) decreases the number of critical time gaps to the leading vehicle</td>
<td>EBA analysis of event frequencies (instances of time headway/TLC/TTC shorter than X) per mileage/time driven/no of drivers</td>
</tr>
<tr>
<td></td>
<td>SL (resp. CC) use increases over time</td>
<td>Time series based EBA analysis of SL (resp. CC) activation occurrences (total number of activations per X hours of driving)</td>
</tr>
<tr>
<td></td>
<td>Using CC, driver’s reaction time (time to reach the brake pedal) will increase.</td>
<td>Time series based ABA analysis of SL (resp. CC) activation time (total time in use per X hours of driving)</td>
</tr>
</tbody>
</table>

### CSW

<table>
<thead>
<tr>
<th>CSW</th>
<th>Loss of control due to high speed in curves</th>
<th>Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSW</td>
<td>Using CSW, the mean curve entrance speed for speeds above speed limit will be reduced</td>
<td>EBA analysis of curve entrance speed selection in baseline and treatment</td>
</tr>
<tr>
<td>Method</td>
<td>Crash Type</td>
<td>Hypothesis</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>FEA</td>
<td>No particular crash type</td>
<td>No specific safety related hypothesis posted (i.e. no posited link between reduced fuel consumption and crash reduction)</td>
</tr>
<tr>
<td>SafeHMI</td>
<td>All crash configurations near intersections and road exits and entrances</td>
<td>Using SafeHMI, the number of crashes, near crashes, and incidents at or near navigation decision points will decrease</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Using SafeHMI, the there will be a general reduction in mileage on unfamiliar routes</td>
</tr>
</tbody>
</table>
### 2A.3: Hypothesis under consideration for testing by means of objective data to aid the efficiency impact calculation

<table>
<thead>
<tr>
<th>No.</th>
<th>Hypothesis</th>
<th>Function group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Longitudinal</td>
</tr>
<tr>
<td>1</td>
<td>The average speed will decrease</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>The number of trips made will increase</td>
<td>✓</td>
</tr>
<tr>
<td>3a</td>
<td>The number of vehicle km travelled will increase (tested with subjective data)</td>
<td>✓</td>
</tr>
<tr>
<td>3b</td>
<td>The number of vehicle km travelled will increase (to be tested per road category, with objective data)</td>
<td>✓ (✓)</td>
</tr>
<tr>
<td>4</td>
<td>The amount of recurrent delay (e.g. daily congestion in peak hours) in the network will decrease</td>
<td>✓ (ACC and SL/CC)</td>
</tr>
<tr>
<td>5</td>
<td>The amount of incidental (accident-related) delay in the network will decrease</td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>The travel times will decrease</td>
<td>✓</td>
</tr>
</tbody>
</table>
2A.4: Hypothesis under consideration for testing by means of objective data to aid the environmental aspects impact calculation

<table>
<thead>
<tr>
<th>Nr</th>
<th>Hypothesis</th>
<th>Function group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Longitudinal</td>
</tr>
<tr>
<td>1</td>
<td>The average speed will decrease</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>The number of trips made will increase</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>The number of vehicle km travelled will increase (to be tested per road category)</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>The fuel consumption will decrease</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>The CO$_2$ emissions will decrease</td>
<td>✓</td>
</tr>
</tbody>
</table>
Annex 2B:
Hypotheses Testing for Objective FOT Data – Elaborated Examples

EXAMPLE 1: FOR HYPOTHESIS “ACC USE INCREASES OVER TIME”

**Analysis plan for hypothesis:** ACC use increases over time

<table>
<thead>
<tr>
<th>Access Database</th>
<th>Select Data</th>
<th>Data Processing</th>
<th>Chunk Data</th>
<th>Calculate PI</th>
<th>Merge PI</th>
<th>Stats</th>
<th>Check Correlations</th>
<th>Check Outliers</th>
<th>Check Videos</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre-processing</td>
<td></td>
<td></td>
<td>Derived measures filtering</td>
<td>Churning</td>
<td>Performance Indicators</td>
<td>Merging</td>
<td>Statistical Analysis</td>
</tr>
</tbody>
</table>

**Attributes**

- **Hypothesis id:** ACC – U1
- **Creation date:** 2009-11-12
- **Creator:** MD
- **Status:** F – euroFOT
- **Version:** [1.7]
- **Access:** [leave blank]

**Pre-processing:**

No specific pre-processing needed.

**Comparison situations:**

- Treatment (ACC available): oDBdata.oSegmentInfo.bBaseline = 0 (treatment)

**Controlled factors:**

ACC activation feasibility definition:

Data should be filtered based on:

- oDBdata.voMeasureData.mVehicleSpeed > 30 km/h
- oDBdata.voMeasureData.mTrafficDensity (congestion) = medium or low; if this measure is available – N.A. on 110126

Driver identity definition: it is required for the data to be organized on a driver basis using the DriverID because increase in usage is driver-based (driverID is a within-subjects variable).

**Quality check:**

- oDBdata.oSegmentInfo.oTripQuality.iLongEnough = 1 (at least 120s)
- oDBdata.oSegmentInfo.oTripQuality.iQualityImportantMeasure = 1 (velocity available)
- oDBdata.oMeasureInfo.mACCstate.iQuality = 1 (ACC ok)
- oDBdata.oSegmentInfo.oTripQuality.iTripDistance = 1 (at least 0.1 km)
- oDBdata.oSegmentInfo.oTripQuality.iCAN_available = 1 (data from CAN available)

**Analysis plan for hypothesis:**

ACC use increases over time

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Creation date</th>
<th>Creator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothesis id: ACC – U1</td>
<td>2009-11-12</td>
<td>MD</td>
</tr>
</tbody>
</table>

**Pre-processing:**

No specific pre-processing needed.

**Comparison situations:**

- Treatment (ACC available): oDBdata.oSegmentInfo.bBaseline = 0 (treatment)

**Controlled factors:**

ACC activation feasibility definition:

Data should be filtered based on:

- oDBdata.voMeasureData.mVehicleSpeed > 30 km/h
- oDBdata.voMeasureData.mTrafficDensity (congestion) = medium or low; if this measure is available – N.A. on 110126

Driver identity definition: it is required for the data to be organized on a driver basis using the DriverID because increase in usage is driver-based (driverID is a within-subjects variable).

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- oDBdata.oSegmentInfo.oTripQuality.iQualityImportantMeasure = 1 (velocity available)
- oDBdata.oMeasureInfo.mACCstate.iQuality = 1 (ACC ok)
- oDBdata.oSegmentInfo.oTripQuality.iTripDistance = 1 (at least 0.1 km)
- oDBdata.oSegmentInfo.oTripQuality.iCAN_available = 1 (data from CAN available)
**Chunking:**

The data, according to the selection criteria described so far, should be chunked in:

- **3-minute** long chunks for each data segment

*Note: a sensitivity analysis can be done on chunk size to make sure most of the data is used. A plot of the distribution of segment-length may help individuating the optimal chunk size. However, it seems reasonable to exclude very short chunks since ACC was not designed to be used for very short periods of time.*

**Performance indicators:**

For each chunk, the PI from the function `form2p_PercACCuse` should be calculated and saved. Further the date of the trip should be also saved for each chunk as a second PI. `PercTimeACCuse` is just `length(chunk)/length(oDBdata.voMeasureData.mACCState= active 3 for VCC 1 and 2 for VOLVO | ACC_State= stand-by 2 for VCC and 4 for VOLVO)* sample_frequency`.

**Merging:**

PIs may be merged on different time windows (numbers of chunks) with a simple mean() function. Specifically averaging `PercTimeACCuse` over chunks keeping in mind that in this hypothesis the merging function does not need to provide a single value but always a vector of values (we are interested in trends).

**Statistical analysis:**

Visual inspection may be necessary to determine which stat and on which time windows should be applied.

An **autocorrelation** analysis may be used to see if there is any pattern in the usage.

**MANCOVA** (paired according to drivers ID; time as continuous variable and PercTimeACCuse as categorical) may be used to find an ideally positive regression line over time while keeping into account controlled factors (if available).

By including variable factors as factors in the MANCOVA, it can be possible to find out if any factor influenced a possible increase in use overtime.

**Variable factors (confounding) analysis:**

To be coupled to each chunk:

- **Rush hour:**
  - `form2p_RushHours` (Compare the amount of data at different times of the day from `oDBdata.voMeasureData.mFixTime` in rush hours (07:00-09:00 or 16:00-18:00) during week days and non-rush hours (rest of time)).

- **Road type:**
  - NA 100126

- **Weather:**
  - `oDBdata.voMeasure.mRain [0, no rain; 1, light rain; 2, moderate rain; 3, heavy rain]` for VCC
  - `oDBdata.voMeasure.mAmbientTemp [low: <= 3 degrees; high: > 3 degrees], oDBDdata.voMeasure.mAmbientLightCond [1 night; 0 day]`.

- **Impairment of the driver [only VCC]**
  - Compare the distribution of **Driver_Impairment** (1-5 on IW scale) – NA 100126
- Traffic density
  - Check correlation in between oDbdata.voMeasureData.mTrafficDensity (low, medium) and use (assumption is that in days where traffic was very dense occasions of using ACC were less). NA - 100203
- How familiar is the driver with the road
  - Probably not available. Make a disclaimer in the final report. NA - 100126

**Outlier analysis:**
Sudden drops in ACC use as well as sudden peaks in ACC use should be looked in details in order to determine whether they were triggered by environmental factors or driving behaviour.

**Manual check of video:**
No manual check for videos is at the moment foreseen for this hypothesis.

**Relevant measures for testing this hypothesis**
- bBaseline
- mVehicleSpeed
- iLongEnough
- iQualityImportantMeasure
- iTripDistance
- iCAN_available
- mACCState.iQuality
- mFixTime
- mAmbientTemp
- mAmbientLightCond

**Meta data:**
TripIDGeneratingPI (see map below) shall be saved for each PI generated in order to enable efficient debugging of possible errors in the data base.
DriverID as reported in the data base shall also be saved in the metadata branch.

**Used and discarded data:**
We shall keep track of missing/discarded data as well as of the data actually used in data analysis. According to the map below:

7) MissingData shall be calculated, in seconds for each variable factor and should be reported as cumulative for each driver.

8) DiscardedTimeForChunking shall be calculated, in seconds for each driver as a cumulative of all data lost in chunking (either because it was left out or because the data sample was too short to account for one chunk).

9) DiscardedDataForLowQuality shall be calculated, in seconds for each driver as a cumulative of all data with not enough good quality.

10) OtherDiscardedTrips: all tripIDs not possible to process because the driver was not
recognizable should be saved here.

11) UsedDataPerDriver shall be calculated, in seconds for each driver as a cumulative of all data used to calculate PIs.

12) TotalUsedTime shall be calculated as the sum of all UsedDataPerDriver from all drivers (it is a redundant measure that can be calculated in the end of the analysis)

Possible representations of the data:
Expected data structure:
Expected PI matrixes for stats (ANCOVA) paired:

- DriverID and trend of %TimeACCuse over time

<table>
<thead>
<tr>
<th>Controlled factor 1</th>
<th>%TimeACCuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver 1</td>
<td>%ACC(1), %ACC(2), …, %ACC(n)</td>
</tr>
<tr>
<td></td>
<td>%ACC(1), %ACC(2), …, %ACC(n)</td>
</tr>
<tr>
<td>Driver 2</td>
<td>%ACC(1), %ACC(2), …, %ACC(n)</td>
</tr>
<tr>
<td></td>
<td>%ACC(1), %ACC(2), …, %ACC(n)</td>
</tr>
<tr>
<td>…</td>
<td>%ACC(1), %ACC(2), …, %ACC(n)</td>
</tr>
<tr>
<td></td>
<td>%ACC(1), %ACC(2), …, %ACC(n)</td>
</tr>
</tbody>
</table>

Alternative ways to combine usage over time before statistical analyses:

1) %RelativeTime (this example)

Explanation: PI (%TimeACCuse) is calculated over chunks of equal time length.

Pros: assumes that changes over time depend only on how long the driver drives (the driver can go on vacation and this time will not be counted).

Cons: there is no fair way to represent the result on a year time scale. It does not take into account how interruptions of driving sessions may play a role in getting use to ACC.

2) %Trip

Explanation: PI is calculated for each trip.

Pros: takes into account that interruptions of trip may play a role in getting use to ACC. No data is discarded by chunking (since chunking is not necessary).

Cons: a long drive and a short one count in the same way. Since long drive and short drive may be correlated to road type, this may confound a little bit the results. Further, it is difficult to fairly average across drivers. Finally, it assumes that the driver drives the same time every day.

3) %AbsoluteTime

Explanation: PI is calculated for each day.

Pros: it is possible to represent data on a year base as one would expect. No data is discarded by chunking (since chunking is not necessary).

Cons: weekends and day-off may need to be worked out. If vacation is in August, August data may be less significant than in the other month. Further, it is difficult to fairly average across drivers. Finally, it assumes that the driver drives the same time every day.
4) **Occurrences**

*Explanation:* PI is an event (%TimeACCuse in this example becomes #ACCactivations), occurrences of this event are calculated over each trip, segment, or chunk.

**Pros:** data may not be discarded if no chunking is needed (which is likely since events normally happen on a longer time scale than the one needed to process a PI and, as a consequence may better be applied to trip- or segment-based analysis.

Further, this takes into account (in this example) short activation of ACC. This can be useful if we assume that, in the beginning, the driver will use ACC only on motorways (= long time trips) and later one also on rural road (= shorter-time trips). If this assumption is true, analysis 1, 2, and 3 may fail to show this result which would be very relevant.

*Cons:* it may not be fair to consider only occurrences, it is likely that each event will need further information (for instance, in this example, how long time did the specific event last). Taking into account this second PI in the PI matrix will increase complexity and may end up complicating the merging procedure.

5) **Hybrid of 1, 2, 3, and 4**

*Explanation:* analysis methods 1, 2, 3, and 4 can be combined. For instance, %Time from analysis 1 can be combined with %AbsoluteTime from analysis 3 so that data can still be plotted on a year base but it is possible to dig and understand how significant are the data and if the assumption on equal amount of driving everyday from analysis 3 is actually valid. In this example 1 and 3 can be combined since date of the trip is saved for each chunk as a second PI.

**Pros:** combining analysis often means to keep the pros from both

**Cons:** the data set gets complicate and chunking and merging may need to be applied differently to virtually distinguished data sets.
EXAMPLE 2: FOR HYPOTHESES “ACC DECREASES AVERAGE SPEED”

**Analysis plan for hypothesis:** ACC decreases average speed

<table>
<thead>
<tr>
<th>Access Database</th>
<th>Select Data</th>
<th>Data Processing</th>
<th>Chunk Data</th>
<th>Calculate Pi</th>
<th>Merge Pi</th>
<th>Sorts</th>
<th>Check Correlations</th>
<th>Check Outliers</th>
<th>Check Robust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>Presorting</td>
<td>Derived measures</td>
<td>Filtering</td>
<td>Performance Indicator</td>
<td>Merging</td>
<td>Statistical Analysis</td>
<td>Variable factors</td>
<td>Outliers analysis</td>
<td>Manual check of validity</td>
</tr>
</tbody>
</table>

**Attributes**

- **Hypothesis id:** ACC - S13
- **Creation date:** 2011-02-17
- **Creator:** MD
- **Status:** F
- **Version:** 1.6
- **Access:** [leave blank]

**Pre-processing:**

A filter with hysteresis should be applied on \( m\text{VehicleSpeed} \). (Since \( m\text{VehicleSpeed} \) will be also a controlled factor used to select the data it is important that spikes in speed do not result in fragmenting data).

This filter is supposed to help filtering 3 speed ranges (low: below 50 km/h, medium: between 50 and 70 km/h, and high: above 70 km/h) so it needs to take into account the speed thresholds: 1) 50 km/h and 2) 70 km/h and acknowledge a change in speed range when speed is below/above one of this threshold for at least 10s.

This filter is used to limit data fragmentation by neglecting changes in speed range when shorter than 10s. Note: this filter is used to make possible chunking of longer segments which make possible to use longer chunks.
Comparison situations:
- Baseline (NO ACC available): \textit{experimental condition} = \textit{baseline}
- Treatment (ACC available and in use): \textit{experimental condition} = \textit{treatment} AND \textit{mACCState} = \textit{active} (for VCC: \textit{mACCState} = 3)

Controlled factors:

ACC activation feasibility definition:
Data should be filtered based on:
- \textit{mVehicleSpeed} > 30 km/h
- No congestion – (\textit{Traffic\_Density} = \textit{medium} or \textit{low}; if this measure is available) (for VCC possible to use is: \textit{mTraffic\_Intensity})
- Not during \textit{overtaking} manoeuvre (definition of overtaking from event matrix SP4) (event \textit{eOvertaking})
- ACC is not overridden – i.e. if ((\textit{mAccelPedalPos} \approx 0) AND (\textit{mACCState} = \textit{active})) data should not be considered.

Driver identity definition: Ideally data should be organized on a driver basis using the DriverID (so that comparison situation can be used in the stat as within factor with repeated measures). However, if not possible data can be organized on a vehicle basis (VehicleID). Statisticians will need to evaluate in this case the extent to which a within stat is appropriate.

Driver experience definition:
Drivers should be clustered according to 2 levels of experience
- Experience:
  - \textit{Low}: \textit{Driving\_exp} < 5 years
  - \textit{High}: \textit{Driving\_exp} \geq 5 years

Driver gender [only VCC]:
Drivers should be clustered according to the 2 genders \textit{Gender}
- \textit{M} or \textit{F}

Velocity range definition:
Data should be organized based on 3 velocity ranges (after applying hysteresis filter)
\textit{Low}: \textit{mVehicleSpeed} < 50 km/h
\textit{Medium}: \textit{mVehicleSpeed} > 50 km/h AND \textit{mVehicleSpeed} < 70 km/h
\textit{High}: \textit{mVehicleSpeed} > 70 km/h

Quality check/classification
- Measure listed below should be available and not corrupted (probably this can be assured by making sure that \textit{oQuality.iMeasureValid} = 1).

Chunking:
Data should be chunked. Optimal chunk size should be calculated according to the procedure below. Based on previous analysis chunks may result to be 1- to 10- minutes long. Chunk size is a determinant decision which may influence the results and the amount of data.
utilized for the analysis. The optimal chunk size (for this specific hypothesis) is a trade off in between too long: very reliable for PI but wasting data and too small: not reliable for PI calculation but able to utilize most of the data. Plotting distributions of chunk size (following Figure) may help the analyst to find the optimal compromise for chunk size.

By looking at this Figure, the analyst can understand how much data is discarded as a function of the segments time-length. Specifically, it appears that choosing 25s-long chunks would result in using only 20% of the data.

If the previous Figure can help the analyst to decide what is the maximum acceptable chunk-size, information about the PI and the dynamics captured by the PI can be used to set a minimum acceptable chunk-size. For example standard deviation of lane offset may be reliable only if calculated on chunks at least 10s long.

\textit{mean velocity} is not a PI very sensitive and it can be calculated over a very limited number of samples; therefore taking into consideration most of the data. However, as a second trade off factor, it should be noticed that the smaller are the chunks, the more computation time and RAM are necessary.

\textbf{Performance indicators:}

For each chunk the PI: \texttt{fotm2p\_average\_speed} - \textit{mean velocity} according to the definition in the PI matrix should be calculated.

\textbf{Merging:}

The mean of all mean velocity PIs from each chunk should be saved in the final Matlab structure which may be similar to the example presented in \textit{Possible representations of the data}, below.
**Statistical analysis:**
ANOVA repeated measures (DriverID) with as 2 main within factors the following combinations:
- 1) baseline/treatment and 2) speed ranges
Or one within and one between factor according to the following combinations
- 1) baseline/treatment and 2) driver experience
- 1) baseline/treatment and 2) driver gender

**Variable factors analysis:**
Based on the results from the statistical analysis it may be good to compare that the following variable are equally distributed in the data sets especially where statistical significance have been found. This means that for each chunk the following variable factors should be added up in the merging procedure.
- Rush hour:
  - DriversRushMeasurement
    - Rush measurement: Compare the amount of data at different times of the day from of mFixTime in rush hours (07:00-09:00 or 16:00-18:00) during week days and non-rush hours (rest of time)
- How familiar is the driver with the road
  - Probably not available. Make a disclaimer in the final report.
- Road type:
  - Compare the amount of time spent in rural versus motorways (RoadType)
- Level of sensation seek [only VCC]:
  - Compare the Driver_Type of the drivers considered in the analysis. Driver type can be SensationSeekers or non-SensationSeekers according to questionnaires of it may come from a specific analysis of the data. At the moment this point is still open to discussion.
- Weather:
  - Compare the distribution of Weather situational variables (rain, low temperature (below 3°C), darkness) from the weather-related measure

**Outlier analysis:**
No outliers’ analysis is foreseen for this hypothesis.

**Manual check of video:**
No manual check for videos is at the moment foreseen for this hypothesis.

**Relevant measures for testing this hypothesis**
- mVehicleSpeed
- timeindex,
- mACCState,
- mAmbientTemp
- dTimeAbsSerial
- mAccelPedalPos
Deliverable D6.2
Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment

- mFixTime
- mTrafficIntensity
- oQuality.iMeasureValid
- experimental condition
- DriverID and/or VehicleID
- Driving_exp
- RoadType (rural roads, motorway)
- Driver_Type (sensation-seeker, non-sensation seeker)
- Weather (rain, low temperature, darkness)

**Meta data:**
TripIDgeneratingPI (see map below) shall be saved for each PI generated in order to enable efficient debugging of possible errors in the data base.

DriverID as reported in the data base shall also be saved in the metadata branch.

**Used and discarded data:**
We shall keep track of missing/discarded data as well as of the data actually used in data analysis. According to the map below:

13) MissingData shall be calculated, in seconds for each variable factor and should be reported as cumulative for each driver.

14) DiscardedTimeForChunking shall be calculated, in seconds for each driver as a cumulative of all data lost in chunking (either because it was left out or because the data sample was too short to account for one chunk).

15) DiscardedDataForLowQuality shall be calculated, in seconds for each driver as a cumulative of all data with not enough good quality.

16) OtherDiscardedTrips: all tripIDs not possible to process because the driver was not recognizable should be saved here.

17) UsedDataPerDriver shall be calculated, in seconds for each driver as a cumulative of all data used to calculate PIs.

18) TotalUsedTime shall be calculated as the sum of all UsedDataPerDriver from all drivers (it is a redundant measure that can be calculated in the end of the analysis)
**Possible representations of the data:**

*Expected data structure:*

Note: “Driver” should be replaced with “Vehicle” if Driver is not identifiable. In this case, Gender, DriverExp, and DriverType should related to the most probable driver (in case there is clear evidence that is the usual driver), it is clear however that if there is no certainty about who is driving data may not be suitable for 1) driver-specific analysis and 2) repeated measures stats.

**Expected PI matrixes for stats:**

- baseline/treatment and 2) speed ranges

<table>
<thead>
<tr>
<th></th>
<th>mVehicleSpeed &lt; 50 km/h</th>
<th>mVehicleSpeed &gt; 50 km/h AND mVehicleSpeed &gt; 70 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver 1</td>
<td>Treatment</td>
<td>x km/h</td>
</tr>
<tr>
<td></td>
<td>Baseline</td>
<td>x km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x km/h</td>
</tr>
<tr>
<td>Driver 2</td>
<td>Treatment</td>
<td>x km/h</td>
</tr>
<tr>
<td></td>
<td>Baseline</td>
<td>x km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x km/h</td>
</tr>
<tr>
<td></td>
<td>Baseline</td>
<td>x km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x km/h</td>
</tr>
</tbody>
</table>
### Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment

- baseline/treatment and 2) driver experience

<table>
<thead>
<tr>
<th>Driver 1</th>
<th>Driver_exp</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>&lt;5 or &gt;5</td>
<td>x km/h</td>
</tr>
<tr>
<td>Baseline</td>
<td>&lt;5 or &gt;5</td>
<td>x km/h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Driver 2</th>
<th>Driver_exp</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>&lt;5 or &gt;5</td>
<td>x km/h</td>
</tr>
<tr>
<td>Baseline</td>
<td>&lt;5 or &gt;5</td>
<td>x km/h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>…</th>
<th>Driver_exp</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>&lt;5 or &gt;5</td>
<td>x km/h</td>
</tr>
<tr>
<td>Baseline</td>
<td>&lt;5 or &gt;5</td>
<td>x km/h</td>
</tr>
</tbody>
</table>

Note: this second analysis needs for drivers to be identified.

- baseline/treatment and 2) driver gender

<table>
<thead>
<tr>
<th>Driver 1</th>
<th>Driver_gender</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>M or F</td>
<td>x km/h</td>
</tr>
<tr>
<td>Baseline</td>
<td>M or F</td>
<td>x km/h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Driver 2</th>
<th>Driver_gender</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>M or F</td>
<td>x km/h</td>
</tr>
<tr>
<td>Baseline</td>
<td>M or F</td>
<td>x km/h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>…</th>
<th>Driver_gender</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>M or F</td>
<td>x km/h</td>
</tr>
<tr>
<td>Baseline</td>
<td>M or F</td>
<td>x km/h</td>
</tr>
</tbody>
</table>

Note:

<table>
<thead>
<tr>
<th>Baseline (Driver can NOT activate ACC)</th>
<th>Treatment (Driver can activate ACC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC off</td>
<td>ACC off</td>
</tr>
<tr>
<td>CC off</td>
<td>CC on</td>
</tr>
</tbody>
</table>
EXAMPLE 3: FOR HYPOTHESES “USING ACC+FCW, THE NUMBER OF FORWARD CRASHES, NEAR CRASHES AND INCIDENTS WILL DECREASE”

### Analysis plan for hypothesis:
Using ACC+FCW, the number of forward crashes, near crashes, and incidents will decrease.

### Attributes:

<table>
<thead>
<tr>
<th>Hypothesis id: ACC+FCW – S1</th>
<th>Creation date: 2011-02-17</th>
<th>Creator: LM</th>
</tr>
</thead>
</table>

### Pre-processing:
No additional pre-processing steps must be performed. Incidents will be obtained from the euroFOT safety impact chain (described in deliverables D6.2 and D6.4). The following steps of the safety impact methodology are especially relevant as background information for the present hypothesis:

1. Longitudinal use case scenario calculation;
2. Event detection;
3. Event annotation and severity ranking.

### Comparison situations:
- Baseline (NO ACC available) : oDBdata.oSegmentInfo.bBaseline = 1
- Treatment (ACC available) : oDBdata.oSegmentInfo.bBaseline = 0

### Controlled factors:
Identity definition: it is required for the data to be organized on a driver basis using the DriverID (driverID is a within-subjects variable). Nevertheless, in case multiple drivers share the same id, i.e., more than one driver driving in the same trip, VehicleID should be used instead.

#### Weather:
Different binary options are available:
- oDBdata.voMeasure.mRain [dry (0, no rain); not dry (1, light rain; 2, moderate rain; 3, heavy rain)] for VCC.
- oDBdata.voMeasure.mAmbientTemp [low: <= 3 degrees; high: > 3 degrees], oDBDdata.voMeasure.mAmbientLightCond [1 night; 0 day]).

Note that the following controlled factors are already included in the longitudinal use case scenario definition: intersection or roundabout (inside/outside), road shape (curve/not a curve), posted speed (low/high).

### Quality check/classification:
No further quality check is needed provided that incidents will be available from the safety impact processing chain.

### Chunking:
No chunking is required since this hypothesis deals with discrete events.
**Performance indicators:**
The number of valid incidents per kilometre will be used as PI. PIs will be arranged by event severity (defined in annotations).

**Merging:**
No merging required.

**Statistical analysis:**
- Repeated measures ANOVA \( (\text{VehicleID}) \). Dependent variable: risk (events / km); independent variables: controlled factors.

**Variable factors (confounding) analysis:**
- **Rush hour:**
  - \( \text{fotm2p\_RushHours} \) (Compare the amount of data at different times of the day from \( \text{oDBdata\_voMeasureData.m\_FixTime} \) in \( \text{rush\_hours} \) (07:00-09:00 or 16:00-18:00) during week days and \( \text{non-rush\_hours} \) (rest of time) for baseline and treatment).
  - **Impairment of the driver [only VCC]:**
    - Compare the distribution of \( \text{Driver\_Impairment} \) (1-5 on IW scale) for baseline and treatment – NA 100126
  - **Traffic density:**
    - Compare the distribution of \( \text{oDbdata\_voMeasureData.m\_TrafficDensity} \) (low, medium) for baseline and treatment. NA - 100203
  - **Trailer load [only Volvo]:**
    - Compare the distribution of \( \text{oDbdata\_voMeasureData.m\_GrossCombVhlWeight} \) (vehicle + trailer weight) for baseline and treatment.

**Outlier analysis:**
No outlier analysis is foreseen for this hypothesis.

**Manual check of video:**
Not necessary provided that valid events will be available from the safety impact processing chain.

**Relevant measures for testing this hypothesis**
- \( \text{bBaseline} \)
- \( \text{mRain} \)
- \( \text{mAmbientLightCond} \)
- \( \text{mFixTime} \)
- \( \text{mAmbientTemp} \)
- \( \text{mTrafficDensity} \)
- \( \text{mGrossCombVhlWeight} \)
Possible representations of the data:
Expected data structure:
Example of expected PI matrix for stats for a given incident severity:

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Controlled factors</th>
<th>Events / km in baseline</th>
<th>Events / km in treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weather</td>
<td>Road type (distance in m)</td>
<td>Road curvature</td>
</tr>
<tr>
<td>1</td>
<td>Dry</td>
<td>Distance to intersection or roundabout &lt;= 30</td>
<td>Curve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not a curve</td>
<td>30 &lt;= limit &lt;= 50</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>Distance to intersection or roundabout &gt; 30</td>
<td>Curve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not a curve</td>
<td>30 &lt;= limit &lt;= 50</td>
</tr>
<tr>
<td>1</td>
<td>Not dry</td>
<td>Distance to intersection or roundabout &lt;= 30</td>
<td>Curve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not a curve</td>
<td>30 &lt;= limit &lt;= 50</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>Distance to intersection or roundabout &gt; 30</td>
<td>Curve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not a curve</td>
<td>30 &lt;= limit &lt;= 50</td>
</tr>
<tr>
<td>2</td>
<td>Dry</td>
<td>Distance to intersection or roundabout &lt;= 30</td>
<td>Curve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not a curve</td>
<td>30 &lt;= limit &lt;= 50</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Distance to intersection or roundabout &gt; 30</td>
<td>Curve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not a curve</td>
<td>30 &lt;= limit &lt;= 50</td>
</tr>
<tr>
<td>2</td>
<td>Not dry</td>
<td>Distance to intersection or roundabout &lt;= 30</td>
<td>Curve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not a curve</td>
<td>30 &lt;= limit &lt;= 50</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Distance to intersection or roundabout &gt; 30</td>
<td>Curve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not a curve</td>
<td>30 &lt;= limit &lt;= 50</td>
</tr>
</tbody>
</table>
Annex 2C:
Hypotheses Testing for Subjective FOT Data – Elaborated Examples

Example 1: analysis plan for hypothesis “Sensation seeker drivers will perceive the warnings from FCW as annoying”

Items used
Items under per_1_1 and items relating to warning timing (xxx_eas_1s_4 and xxx_eas_1u_4) and irritation (eas_1r_4).

Analysis, coding and presentation
There are 20 items in the Arnett Sensation Seeking Scale, coded 1-4. There are two subscales, intensity and novelty, consisting of 10 items each. Items 1,4,5,7,8,9,11,12,14,15,16,18,19 & 20 are reversed such that a high score=higher sensation seeking. Here we are assuming that the hypothesis refers to the work of Jonah that suggests that high sensation seekers follow at shorter distances. It is therefore assumed in this hypothesis that high sensation seekers will report the visual and auditory warnings as being too early.

Note that the spreadsheet provided contains formulae that reverse the ordering of some items. Insert the raw data in the upper half; the data will be reversed in the lower half.

The spreadsheet first calculates the sum of Novelty scores (10 items) and Intensity scores (10 items) for each participant. It then calculates the total score across the two scales.

These can then be correlated with measures relating to warning timing (eas_1r_4, eas_1s_4, eas_1u_4). Correlations can be carried in a statistical package and the results reported.

Example 2: analysis plan for hypothesis “Acceptance changes over time with function use”

Items used
Items under xxx_ac_1_2, xxx_ac_1_3 and xxx_ac_1_4

Analysis, coding and presentation
Use the Van der Laan scale administered in Time 3 and 4. The hypothesis can also be interpreted as suggesting that acceptability changes once the function has been used. The Time 2 (before use) data can be used as well.

Further analysis can be undertaken with the additional acceptability items if required (although not essential for this hypothesis).

The 9 items are coded +2 to –2 and separated into factors of usefulness and satisfaction and presented as below in Figure 27.
Conduct t-tests comparing the usefulness and satisfaction results in Time 3 v Time 4. Undertake ANOVA if including Time 2 data.

**Example 3: analysis plan for hypothesis “Certain features of the functions, in terms of usability, influence acceptance”**

**Items used**
- Items under xxx_eas_1_4.

**Analysis, coding and presentation**

Maximum of 34 items were presented in the questionnaire under the heading of Perceived Ease of Use. Depending on the design of the function, some items will not have been relevant and therefore omitted by the VMCs. The items are coded 1-5, but recoded to -2 to +2 (to match the Van der Laan coding).

Each participant is then considered separately such that, if a participant scored the function positively on the Van der Laan (>0), then those items that score high on usability were deemed to have impacted on that score. Conversely, if a participant scores the function negatively on the Van der Laan (<0) then there would be certain items relating to usability that would contribute to this.

The spreadsheet reverses the items that need to be reversed, recodes them and then uses IF and AND statements to create the graphs (see below).
Look for the peaks in both the negatives and the positives. The height of the red bars indicates the likelihood that a "negative" participant rated the function as negative on that particular item. A "negative" participant is one whose average acceptability score is negative.

The height of the green bars indicates the likelihood that a "positive" participant rated the function as positive on that particular item. A "positive" participant is one whose average acceptability score is positive.

Annex 3  Specification of situational variables

Situational variables are variables that describe the circumstances at a certain moment. SP 4 ‘Experimental Procedures’ has defined situational variables in D4.1 Performance indicators, annex 5. A subset of these situational variables is used for the impact assessment. These specifications of the situational variables have been further specified for the impact assessment in a harmonised way for all VMCs. This specification is shown in the table below. Some vehicles have different sensors than others, which might result in a different specification of the situational variable, e.g. when lighting sensors are not available, the time of the day will be used to determine the lighting condition. Any

<table>
<thead>
<tr>
<th>variable</th>
<th>categories</th>
<th>default specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function state</td>
<td>Baseline</td>
<td>Function specific</td>
</tr>
<tr>
<td></td>
<td>On</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Active</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Event (warning)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Off</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Passive</td>
<td></td>
</tr>
<tr>
<td>Road type</td>
<td>Motorway</td>
<td>Dual-carriageway roads, with a minimum of two lanes in each direction AND grade-separated access.</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>Road that is not a motorway AND not within the boundaries of a built-up area.</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>Non-motorway road within the boundaries of a built-up area.</td>
</tr>
<tr>
<td>Speed limit</td>
<td>&lt;=30</td>
<td>&lt;=30</td>
</tr>
<tr>
<td></td>
<td>&gt;30, &lt;=50</td>
<td>&gt;30, &lt;=50</td>
</tr>
<tr>
<td></td>
<td>&gt;50, &lt;=80</td>
<td>&gt;50, &lt;=80</td>
</tr>
<tr>
<td></td>
<td>&gt;80, &lt;=100</td>
<td>&gt;80, &lt;=100</td>
</tr>
<tr>
<td></td>
<td>&gt;100, &lt;=120</td>
<td>&gt;100, &lt;=120</td>
</tr>
<tr>
<td></td>
<td>&gt;120, &lt;=140</td>
<td>&gt;120, &lt;=140</td>
</tr>
<tr>
<td></td>
<td>&gt;140</td>
<td>&gt;140</td>
</tr>
<tr>
<td>Number of lanes</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>&gt;4</td>
<td>&gt;4</td>
</tr>
<tr>
<td>Traffic state</td>
<td>Free flow</td>
<td>t.b.d. (proposal: HW &gt; 60, RR &gt; ??, UR &gt; 18)</td>
</tr>
<tr>
<td></td>
<td>Congestion</td>
<td>t.b.d. (proposal: HW &lt; 60, RR &lt; ??, UR &lt; 18)</td>
</tr>
<tr>
<td>Road curvature</td>
<td>Strong curve</td>
<td>Curve radius &lt; 500m</td>
</tr>
<tr>
<td></td>
<td>Curve</td>
<td>Curve radius &gt; 500 and &lt; 2000 m</td>
</tr>
<tr>
<td></td>
<td>No curve</td>
<td>Curve radius &gt; 2000 m</td>
</tr>
<tr>
<td>Weather</td>
<td>Good</td>
<td>wiper off &amp; temp &gt; 3 °C</td>
</tr>
<tr>
<td></td>
<td>Bad</td>
<td>wiper on or temp &lt; 3 °C</td>
</tr>
<tr>
<td>Lighting</td>
<td>Daylight</td>
<td>from sunrise to sunset (based on time and gps)</td>
</tr>
<tr>
<td></td>
<td>Twilight</td>
<td>not used</td>
</tr>
<tr>
<td></td>
<td>Night (Dark)</td>
<td>from sunset to sunrise</td>
</tr>
<tr>
<td>Link / intersection</td>
<td>Intersection</td>
<td>&lt; 30 m from intersection</td>
</tr>
<tr>
<td></td>
<td>No intersection</td>
<td>&gt; 30 m from intersection</td>
</tr>
<tr>
<td>Vehicle type</td>
<td>Car</td>
<td>all vehicle except MAN and Volvo Trucks</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------------------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Truck</td>
<td>MAN and Volvo Truck vehicles</td>
<td></td>
</tr>
<tr>
<td>Load (for trucks only)</td>
<td>Empty</td>
<td>??</td>
</tr>
<tr>
<td></td>
<td>Loaded</td>
<td>??</td>
</tr>
</tbody>
</table>

For less obvious specifications, an explanation is included:

**Speed limit**
Categories have been defined to be able to compare different roads. The categories have chosen in such a way that similar types of roads categories fall from different countries fall in the same category.

**Traffic state**
A congestion algorithm based on the FOT data/ floating care data is being developed to identify (two) levels of traffic state related to the Levels Of Service (LOS) used in eIMPACT.

**Link / intersection**
A distance of 30 meter around an intersection is used as a threshold for being on a link or on an intersection. This threshold is also used in Swedish accident database Strada. Note that a GPS signal typically has an accuracy of 3 to 9 meters.

**Load (for trucks only)**
The available indicator (for Volvo Trucks) is the weight on back axis, which is not reliable due to different balancing of the load.

**Exceptions from default specification**
As explained above, VMCs may have to divert from the default specification due to limitations of the sensors. These cases are:

- **Swedish VMC:**
  - FOT data from Volvo Trucks is logged only every 30 minutes, so determining situational variables can be a problem
  - For the Volvo Trucks, there is no reliable indicator available for the effect of mass of trucks on the impact of the ACC/FCW. Available indicator is the weight on back axis, which is not reliable due to different balancing of the load. Slope is also disturbing factor for the expected effect of the ACC/FCW.

- **German2 VMC:**
  - For motorways the minimum speed limit is 80 km/h
  - Speed limit > 140 km/h is not used
  - Number of lanes > 4 is not used
  - Curve radius is not measured
  - Lighting (darkness) is coded based on the light sensors in the vehicles
  - For the intersection area 15 meters before and 5 meters after are used. These limits have been set based on video data. A map matching tool gives every small crossroad as intersection, the distance between two intersections can be below 30 meters; intersections can then not be differentiated but merge into one.
French VMC:

- In most of the cases the following speed limits will occur: 30-50-70-90-110-130, but virtually everything is possible such as: 80 km/h (the case for the ‘Périphérique’ road around Paris) or 60 km/h.
- Exotic speed limits (such as 60 and 80 km/h) will be separated and not merged with the classical ones.
- The speed limits are ‘clustered’ as follows:
  - Speed limits $\leq 30 \rightarrow 30$
  - Speed limits $> 30$ and $\leq 50 \rightarrow 50$
  - Speed limits $> 50$ and $\leq 80 \rightarrow 70$
  - Speed limits $> 80$ and $\leq 100 \rightarrow 90$
  - Speed limits $> 100$ and $\leq 120 \rightarrow 110$
  - Speed limits $> 120$ and $\leq 140 \rightarrow 130$
  - Speed limits $> 140 \rightarrow NA$
Annex 4  Descriptions simulation models

PELOPS

PELOPS is a microscopic traffic simulator. It is used for the evaluation of traffic- and infrastructure-supported traffic influence measures and driver assistant systems. The evaluation takes place in form of macroscopic (throughput), microscopic (time gaps, velocities, accelerations) and submicroscopic (fuel consumption, emissions) parameters.

If required, the comprehensive stretch model allows a detailed description of the influences of a stationary traffic environment such as slopes, bends and traffic signs. This environment can be extended by the setting of stretch-dependent traffic environment parameter such as wetness, slippery surface etc.

Figure 28: PELOPS Interaction Scheme

The depiction of the traffic element “driver” is divided into a decision- and a handling model. In the decision model the parameter of the local driving strategy such as speed and lane selection are determined. The handling model converts the characteristics of the local driving strategy into vehicle specific controls for example acceleration pedal position, gear lever etc. The accurate modelling enables a realistic depiction of complex driving manoeuvres such as stop-and-go traffic. This is most of all needed for the investigation of fuel consumption and emissions, and also for the design and analysis of driving assistance systems.
In the vehicle model the controls are converted into dynamic vehicle quantities. The modelling of vehicles is characterised by a high specification degree. The single elements of the drive train such as engine, transmission (manual or automatic), retarder etc. can be specified in a very high accuracy.

PELOPS is provided with a MATLAB® interface which allows the implementation of vehicle models and control algorithms for driver assistance systems. As the vehicle can be reproduced after the cause-effect-principle, also the influences of control technical devices (e.g. distance control, electronic acceleration pedal and brake etc) can be investigated. The aim of the investigation includes vehicle related effects (fuel consumption or emissions) as well as effects on the traffic environment via macroscopic characteristics such as stretch throughput, average velocity and dynamic effects of a convoy of vehicles.

Input PELOPS

The PELOPS input data splits up into several grouped information, provided as plain ASCII files that can be produced either manually or by using a multilingual graphical configuration tool which is, to some degree, self explaining.

The structure of the data to provide can be described in the form of a tree with an unconditioned number of branches, while the leafs actually contain the information. Besides the three main models ‘driver’, ‘vehicle’ and ‘environment’ a further starting branch consists in the general settings. The following listing gives an overview on the main parameters of these items:

- **Driver**
  - The PELOPS’ driver behaviour consists of two models: following behaviour and lane change model. The driver behaviour model can control the strategic, tactical and operational levels of driving.
  - The model of the following behaviour is based on the psycho-physical approach of Wiedemann. Perception thresholds are defined basing on the driving velocity and driver-individual parameters, e.g. estimation abilities and safety need. Depending on the relative velocity and distance to the leading vehicle these perception thresholds subdivide the driving into four parts: uninfluenced driving, approaching, following and braking. Parameters such as...
estimation ability, safety need and daily variation, which are necessary for the determination of those above mentioned variables, have a range between 0 and 1. Those are standardised parameters, which are specified for the entire driver population and uniformly distributed around the average value of 0.5. To overcome the limitations of Wiedemann’s approach, a number of adaptations of the driver model have been made in order to fulfil the requirements of sub-microscopic simulation. So the model in PELOPS has among others the ability, besides the reaction to the direct leading vehicle, to consider foresighted the dominant traffic in front of it, to execute realistically the starting and stopping phases particularly before traffic lights, to show cooperative behaviour to other road users. Different time steps in the consideration of driver assistance systems as well as the modelling of nonlinear procedures in automatic transmissions made it necessary to introduce an adjustable calculation step. Furthermore the model was extended in such a way, that different reaction time of the drivers can be considered. With its characteristics the current version of the driver model can cover the relevant behaviours in the traffic situations on highways, country road and in urban area.

- Besides the following model the PELOPS driver model contains also a lane change model. The structures of all classical lane change models in the time-step-based simulation programs base always on the same pattern. Firstly it checks whether a lane change wish exists at all. Subsequently, it will check whether a possibly existing lane change wish can be realized. After passed assessment the lane change is executed finally. There can be many motivations for lane change. Following a certain route and overtaking are two important motivations. Tactical considerations also lead to a lane change. If a faster vehicle approaches from rear, it could also motivate a lane change to the right lane. In order to keep the type and the number of the representable lane change motivations flexible, in PELOPS a structure for the lane change model was selected, where all motivations are represented by a factor. Furthermore different driver types should also be modelled in the lane change behaviour. The factor, which summarizes the lane change motivations, can be interpreted as satisfaction. In each time step this satisfaction is determined for each driver. Influencing factors are the driver-individual desired velocity in the comparison to the current driving velocity and the velocity on the neighbour lanes. The above mentioned faster vehicle, which approaches from rear, reduces the satisfaction to the own lane and increases the satisfaction to the right lane. The individual satisfactions are summarised by a value, which describes the overall situation. The satisfaction is driver dependent, since the desired velocity is a driver-dependent value.

- Driver-dependent influencing variables in the behaviour model are for example safety need or the estimation ability of distance and velocity. By these parameters it is already possible to model different driver characters (e.g. “sporty driver”). "Safety need" is the most important parameter in the driver model: It affects all distance-dependent behaviours. High safety need means a larger following distance. The size of the gap in the neighbour lane, which is necessary for the overtaking or a lane change procedure, rises likewise with higher safety need. Additionally the choice of velocity is also affected by it. The parameters "estimation ability" and "pedal sensitivity" serve as model inputs for the description of inadequacies of the driver during the estimation of distance or relative speed and the operation of vehicle variables like accelerator pedal, brake pedal and steering. Reaction time is classified in the four categories: standard driving, reaction on the potentially dangerous braking manoeuvre, lane change and starting of the leading vehicle.
Additionally the driver model processes individual levels of compliance of overtaking prohibitions (e.g. right overtaking).

A sporty driver can be described in the simulation with PELOPS for example by low safety need, good estimation ability and high pedal sensitivity. Low safety need of a sporty driver means that basically lower distance are driven and the gaps, which the driver uses for lane change, are significantly smaller than a normal driver. At the same time the sporty driver is willing to accept small distances and gaps, which are impressed to him by the surrounding traffic. Good estimation ability and high pedal sensitivity denote a good controllability of own actions in this context. These two parameters have however only a small influence on the modelled driver behaviour and are less important in comparison to the safety need. Further-more the sporty driver is described by an appropriate parameterisation of the values "reaction time" and "level of compliance". His reaction time is possibly low, likewise his level of compliance for speed limits (i.e. he drives much faster than permitted). Analogue to this ex-ample other "driver types" (safety orientated, economical etc.) can be simulated by a suitable choice of the driver parameters. For the simulation a validated set with hundreds of standard driver types is available in a statistic distribution. Here typical passenger car drivers are covered as well as various types of truck driver.

- Typical individual driver parameters are: Desired velocity, max. possible deceleration, utilisation of vehicle acceleration, safety need, estimation ability, speed limit compliance, compliance of overtaking prohibition, reaction times and lane preference.

  - **Vehicle**
    - PELOPS offers two levels of detail for the internal vehicle models. Common for both models are basic parameters like length, width, cross-sectional area and mass. Both models model the lateral behaviour by means of a single track vehicle model. Concerning the longitudinal behaviour, the detailed vehicle model allows to configure various drive train components such as model engine, clutch or torque converter, gearbox, brakes and tyres.
    - Vehicles can be equipped with ADAS and "sensors" (distance sensor, C2X-components). The number of vehicles equipped with ADAS (i.e. the penetration rate) can be set. Here too, this involves the market penetration but not the usage (that is, activation status and settings) which is taken into account in a separate algorithm. For the specification of the sensors, a functional description of the information provided by the sensors, their capabilities and their limitations will be needed. The ADAS can be very advanced (e.g. real function on a microcontroller integrated by HiL). For euroFOT the use of generic functions is planned.
    - As in ITS modeller, communication is modelled on an aggregate level: messages are sent according to a sending strategy, and arrive with a certain probability and delay, which may depend on the range and possibly other parameters. That is, the modelling does not model the bit-by-bit arrival of a message, nor does it model encoding/decoding, etc. Thus, the communication device needs to be specified on this aggregate level.

  - **Environment**
    - The environment includes the definition of the modelled road (number of lanes, lane width and line markings; straight sections, circular arcs with constant radii or clothoids with constant radii-change; flat sections, inclinations and transition-radii), traffic signs, weather conditions (visibility, friction factor, wind speed, water height) and virtual induction loops.
- **General settings**
  - The general simulation parameters include amongst others the time step of the simulation, the output interval and the duration of the simulation. Furthermore the output data can be specified.

PELOPS provides some useful predefined attributes wherever the user does not want to get involved to much in the complex configuration options the function provides. It is only needed to provide a minimal set of information while it is still possible to change virtually everything that affects the output data.

**Output PELOPS**

For each car that is simulated by the PELOPS, PELOPS generates a great amount of data. Every output parameter can be switched on or off to be scaled to the users needs.

Output can be simple information like position or speed over time, but it is also possible to extract extremely detailed portions of data about the drivers behaviour (e.g. how the driver pushed the gas pedal over time) or about runtime conditions of the engine or the drive train, the input- or output-parameters of the electronic devices, like driver assistance systems, derived values like accelerations or yaw rate and much more.

The following unclosed list gives an impression of what can be obtained from the simulation run:

- **Macroscopic (throughput)**
  - Average speed
  - Traffic flow
  - Traffic density
  - Travel times

- **Microscopic**
  - Longitudinal and lateral position on track, yaw-rate
  - Speeds
  - Accelerations.
  - Headways
  - Time to collision
  - Lane number

- **Sub-Microscopic**
  - Fuel consumption
  - Emissions of CO₂
  - Accelerator, brake and clutch pedal position
  - Engine speed
  - Engine Torque
  - Current Gear
  - Steering Angle

Various statistics for these indicators are possible in a post-process since PELOPS results are stored in ascii-format.

Information on the validation of PELOPS can be found in [42], [43], and [44].
ITS Modeller

ITS Modeller is a microscopic traffic simulator. It uses models for traffic system components (vehicles, drivers, sensors, roadside systems, etc) and lets these components interact in a road network in order to determine the traffic characteristics on the network level.

ITS Modeller is built as a plug-in for commercially available simulators and currently supports Q-Paramics. The behaviour of vehicles and drivers can be adapted as needed, for example to model the effect of ITS functions.

The inputs and outputs of the ITS Modeller are illustrated in Figure 30. In modelling practice, there is a single model that combines vehicle dynamics and driver behaviour in a so-called VDU or Vehicle Driver Unit. In order to model an ITS function, one then needs to know the functional specifications (such as intended use, capabilities and limitations) of the function, and the effect on the driver. In the scheme of Figure 30, the categories “Intelligent vehicle”, “Intelligent roadside” and “Communication” are understood to describe the functional specifications of ITS, whereas the effects of ITS on the VDU are listed under “Driver behaviour”. This is true even when a function intervenes in the driving task. Thus, the term “Driver behaviour” is used because it is easily understood, but should more accurately read “VDU behaviour”.

Figure 30: ITS Modeller logo, showing inputs and outputs of the ITS Modeller

Input ITS modeller

As inputs, the ITS Modeller requires the following components.

- Network:
  - Penetration rate of ITS functions. This involves the market penetration but not the usage (that is, activation status and settings) which is taken into account under driver behaviour. The market penetration is determined by the design of the simulation scenario and hence not a required input from the measurements that are collected in the euroFOT project.
  - Remark: other necessary ingredients are the network geometry and road type characteristics, such as speed limits (this is like any microscopic traffic simulator), and traffic demand, in terms of O-D pairs for passenger cars, vans
and trucks. This information is provided by standard networks available in the ITS Modeller, and is therefore not a required input from the measurements. In order to test different levels of traffic demand, it will be necessary to specify demand levels in the design of the simulation scenarios.

- **Intelligent vehicles:**
  - Specification of sensors: a functional description of the information provided by the sensors, their capabilities and their limitations will be needed.
  - Specification of actuators: a functional description of the important longitudinal, lane change and route choice decision rules of intervening functions will be needed. Decision rules dealing with exceptions are not required as inputs if it can be reasonably expected that they will not impact safety, environment or throughput on the network level. If decision rules are not provided, then perhaps FOT data like speeds, time headways etc. can be used as substitutes.
  - **Remark:** The dynamics of the vehicles themselves are included as a power train model (engine, gear, clutch, slope, friction), and are therefore not a required input from the measurements.

- **Intelligent roadside:**
  - Similar to intelligent vehicles.

- **Driver behaviour:**
  - In the ITS Modeller, driver behaviour consists of three components: longitudinal behaviour, lane change behaviour and route choice behaviour. Lateral behaviour other than lane change behaviour is not modelled. That is, vehicles are modelled as one-dimensional objects. The driver behaviour model can control the strategic, tactical and operational levels of driving, although in applications the operational level is typically not modified from the default ITS Modeller behaviour.
  - Each of the three components needs to include a model that describes the use of ITS applications. For example, if an ACC is present, then there are two longitudinal models, one that describes the longitudinal behaviour of the driver and one that describes the longitudinal behaviour of the ACC. There needs to be a “meta model” that describes the use of the ACC: when it is used, activated, overridden and deactivated, and what settings are chosen.
  - Longitudinal model. The model for longitudinal behaviour will need to provide:
    - A *probability distribution of intended speeds*. These are the speeds that the driver would choose in a free flow situation. They typically depend on circumstances such as road type, and are given as a probability distribution to model variations in driver characteristics.
    - An algorithm that determines the *desired acceleration*, depending on the headway, the speed difference with the predecessor vehicle(s), and the intended speed. Other parameters may be included as desired.
  - Lane change model. This model decides under what conditions the driver changes lane. There are two kinds of lane changes: mandatory lane changes (if the VDU needs to take the next exit, for example), and voluntary lane changes (to overtake a slower vehicle). Each type requires its own model. These models need to provide a *lane change decision* based on the current vehicle route and the traffic situation around the vehicle.
  - Route choice model: route selection of the VDU. In simulations, two ways are used to model route choice: by using split fractions at each decision point (e.g., at an intersection 20% goes left, 80% goes straight), or by determining routes in their entirety from origin to destination. The ITS Modeller uses the second method, with the option that routes can be changed en route, for example if the VDU receives new traffic information. The model needs to
implement route choice, for example in terms of the cost function that is optimized, or possibly (but less desirable) in terms of the fraction of time that a specific road type is used. The model needs to describe the impact of information (from in-car or roadside systems) on the driver’s route choice.

- **Remark:** For all three models, there is a large freedom in the choice of input parameters that go into the models, and therefore it is hard to describe the input parameters in full.

- **Remark:** All three models will have to be specified for the cases with and without the function, and have to be calibrated on the FOT data. This gives the largest confidence that the impacts that are observed in the simulation are actual impacts of the function, and not due to differences in modelling.

### Communication

- Characteristics of communication devices have to be obtained from the measurements: range vs. error rate (on the message level), delay, and sending strategy. This is not relevant for euroFOT because the functions tested in euroFOT are stand alone.

- **Remark:** in the ITS Modeller, communication is modelled on an aggregate level: messages are sent according to a sending strategy, and arrive with a certain probability and delay, which may depend on the range and possibly other parameters. That is, the modelling does not model the bit-by-bit arrival of a message, nor does it model encoding/decoding, etc. Thus, the communication device needs to be specified on this aggregate level.

### Output ITS Modeller

The output of the ITS Modeller consists of indicators that describe various characteristics of traffic. The ITS Modeller output can be processed to obtain impacts on:

- **Throughput:** ITS Modeller produces indicators for speeds and travel times:
  - Speeds.
  - Travel times.
  - Travel time losses (that is, delays).
  - Route choice.

- **Safety:** ITS Modeller produces indicators for surrogate safety measures:
  - Speeds.
  - Headways.
  - Accelerations.
  - Time to collision.

- **Environment:** Emissions of CO$_2$, NO$_x$ and PM$_{10}$ are obtained through post processing with VERSIT+. ITS Modeller computes noise. The following indicators are produced by the ITS Modeller:
  - Speed patterns (speeds as a function of time).
  - Noise.

Various statistics for these indicators are available, such as average, standard deviation, distribution (where applicable). The indicators can be subdivided into categories, for example by road, vehicle type or vehicle equipment type. For specific purposes, other indicators can be added as needed.

### VERSIT+

In order to be able to predict the vehicle emissions in particular traffic situations (e.g. congestion, traffic on intersections, etc.), and to assess the effects of ITS and traffic management, TNO has developed the emission model VERSIT+. VERSIT+ is a statistical emission model that makes an assessment of a vehicle’s emissions based on a very large
database of emission measurements. The next sections will explain how this model can be used in the euroFOT project, what input is needed and what output the model delivers.

**The VERSIT+ emission model [1]**

The dual core of the emission analysis in VERSIT+ consists of a light-duty part, for passenger cars and vans, and a heavy-duty part for light and heavy trucks, buses, and all other vehicles over 3.5 tonnes. Based on an ever increasing number of laboratory measurements, the emission modelling has developed from a simple mean-emission model to a sophisticated statistical analysis. It takes into account vehicle type and particular technology, such as injection technology, catalysts, filters, etc. and their distribution over the fleet. Furthermore, real-world driving cycles (measured speeds over time) which were taken from a large number of traffic situations and traffic control measures (such as speed limits and the degree of enforcement) have improved the driving cycles used for emission measurements. This real-world driving behaviour has been used to determine a number of driving cycles to measure the emissions of vehicles in the laboratory. Hundreds of vehicles from ordinary users were requested and measured each for a number of driving cycles, corresponding to a particular road under particular conditions such as congestion degrees. TNO has, as a result, thousands of measurements over a variety of vehicles and driving circumstances which span together the whole of Dutch traffic situations. In practice, twenty different driving cycles are used to span the Dutch driving behaviour, from heavily congested inner-city traffic, to free-flow motorway driving. The passenger vehicles span 52 different vehicle categories. Even within a particular vehicle category, such as, for example, petrol passenger car, with manual gear, indirect injection, and satisfying the Euro-4 norm, the variation is large. Furthermore, for the same vehicle such variations occur for different driving behaviour. Especially, petrol engines emissions show a large range in emissions. VERSIT+ seeks out the degrees of freedom among the vehicle types and the driving behaviours which actually matter for the average or overall emissions. The emission of one car at one moment in time may exhibit large variations compared to the VERSIT+ average, but with the large number of cars passing a typical point in an hour or day, the comparison is statistically valid. The validation and updating of VERSIT+ occurs on regular basis with the introduction of new vehicle technology, traffic measures, and sample measurements of in-use vehicles.

The heavy-duty vehicles, like trucks, have fewer base categories but they come eventually in more variation due to variations in mass per power, and trailer categories. In total over one hundred vehicle categories, combined heavy-duty and light-duty, are used in VERSIT+, see Figure 31.
Figure 31: The flowchart of VERSIT modelling from the measurements to the Dutch average emissions. The year for which the emissions are predicted plays an important role, primarily in the fleet composition.

A simplified model, VERSIT\textsubscript{+}\textsubscript{micro}, has been developed on the basis of the VERSIT\textsubscript{+} model in order to calculate the emissions for velocity profiles: time-series of velocities of the passing cars. The velocity profiles can be generated by traffic micro-simulation software (ITS Modeller, PELOPS) or be derived from velocity data from vehicles (e.g. GPS data).

**Adaptations needed for the use of VERSIT+ in the EU**

Currently, the model gives data for Dutch car fleets. For euroFOT, the fleet composition (e.g. size of cars, fuel type) probably needs to be adapted to reflect the EU fleet composition (taking into account on which types of vehicles the euroFOT functions will first be installed). The possibilities for this are currently being looked at. Another adaptation that may be needed (depending on whether a large number of km's is made in such a situation or not) is to include a parameter for the gradient, so that the effects of driving in hilly terrain can be taken into account.

**Input**

The input of VERSIT\textsubscript{+}\textsubscript{micro} is a data file listing:

- the vehicle type,
- vehicle number,
- speed and
- distance covered

For each second. In the PI list the speed over time indicator is listed as “speed evolution”.

**Output**

The speed profile for a vehicle is fed into the model which leads to an emission in grams per km. This emission is multiplied by the covered distance of that vehicle such that the emission
in grams is calculated. This calculation is done for each vehicle specified, so that the overall emission for a complete network can be calculated. The components included are: NO\textsubscript{x}, PM\textsubscript{10} and CO\textsubscript{2}.

The following vehicle categories are used (which are based on the average vehicle fleet per category):

- Light duty vehicles
- Heavy Duty Medium vehicles (small trucks, vans, etc)
- Heavy Duty Heavy vehicles (the heavy trucks)
- Buses

Furthermore, a fleet composition for the urban and rural/highway environment has been made for each category to take into account that different types of vehicles drive in the different environments. This is an average of the typical fleet composition on the Dutch roads, in terms of age and technology of the vehicles in a particular year.

N.B. In case the VMCs do not want to share velocity profiles (speed over time, frequency 1-10Hz) with the partners doing the analysis (probably only TNO), it may be possible to let them use the model directly via a web-based module or to let them calculate the parameters needed for the calculations:

- Average speed, and
- A measure for variation in speed named ln(TAD).

See Figure 32 for a graph of NO\textsubscript{x} emissions plotted against the average speed and the ln(TAD) of a drive cycle.

Figure 32: Every single data point represents the emission from one drive cycle (calculated with VERSIT\textsuperscript{+}), plotted against the average speed and the ln(TAD) of that drive cycle.

The grey surface represents the fitted model that is used in VERSIT\textsuperscript{+}\textsubscript{micro}.

**ITS modeller versus PELOPS**

ITS Modeller and PELOPS are both micro simulation tools. They have a couple in things in common, and there are some differences between the models. The similarities are:
• Microscopic models;
• Separate models for each “traffic element” (road network, vehicle model, driver model);
• Input data used for calibrating the baseline / driving without function (see Table 15);
• Output parameters.

There are two main differences with regard to the simulation aspects in euroFOT:

• Integration of the function: PELOPS integrates the functions as a separate function by using the interfaces to the driver and vehicle model. ITS Modeller integrates the functions by adapting the driver behaviour;
• Calculating fuel consumption and emissions: in PELOPS, fuel consumption and emissions are computed using engine maps containing that data. Using ITS Modeller, fuel consumption and emissions are obtained through post processing with VERSIT+.

There is no information available on how well the simulation results of both traffic simulation tools match. Therefore each function will only be simulated in one of the simulation tools. To get this information, a cross validation could be done (this is not part of the project):

• Use the speed pattern output of PELOPS as input for VERSIT+ and compare fuel consumption and emissions of VERSIT+ with the corresponding results of the PELOPS simulation.
• Exchange traffic scenarios (TNO and ika), make simulations with PELOPS and ITS Modeller and compare the simulation results.