D41.1 : Performance Indicators and ecoDriver Test Design

Katja Kircher, Christer Ahlström, Rosa Blanco, Rino Brouwer, Carina Fors, Frank Lai, Guillaume Saint Pierre, David Sánchez, Philipp Seewald

Supporting the driver in conserving energy and reducing emissions

D41.1: Performance indicators and ecoDriver test design

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Authors	Katja Kircher, Christer Ahlström, Rosa Blanco, Rino Brouwer, Carina Fors, Frank Lai, Guillaume Saint Pierre, David Sánchez, Philipp Seewald
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Abstract	This deliverable details the proposed assessment approaches and the design of field trials for data provision. Research questions and objectives of the project were divided into three major themes: user acceptance, behaviour, as well as energy use and emissions, which led to the formation of 24 hypotheses in total. A large number of Performance Indicators were identified,

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	which will be used to validate the hypotheses. These Performance Indicators were grouped into 16 categories, covering the aforementioned three research themes. To provide empirical data for validating the hypotheses and answering the research questions, a series of field trials will be taken place in SP3. There are 12 fleets of vehicles, across 7 countries and covering a wide range of vehicle types. This deliverable outlines experimental design of the field trials, including fleet specifications, participant recruitment, route selection, test procedures, and data collection protocol etc. There are similarities but also individual characteristics of these experimental designs across the fleets and test sites, in order to produce all necessary data for addressing the research questions.

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ecoDriver

Control sheet

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	Name
Prepared by	Katja Kircher
Reviewed by	Rosa Blanco (CTAG) and Jeroen Hogema (TNO)
Authorized by	Katja Kircher
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Glossary of terms

Term	Description
ABA2	Active brake assist 2
ACC	Adaptive cruise control
CC	Cruise control
FCA	Forward collision alert
FEV	Full electric vehicle
GEG	Greenhouse effect gas
HEV	Hybrid Electric Vehicle
ICE	Internal combustion engine
LCA	Lane change assist (also known as blind spot assist)
LCV	Light commercial vehicle (carrier vehicle with a maximum weight of up to 3.5 tonnes
LDW	Lane departure warning
LKA	Lane keeping assist
NV	Night vision
PI	Performance indicator
PRC	Percentage road centre (gaze based performance indicator)
RPM	Revolutions per minute
SL	Speed limiter
SV	Situational variable
TSR	Traffic sign recognition

Acronyms

Acronym	Description
DoW	Description of Work
PI	Performance Indicators

1. Introduction

The main purpose of WP41 was to ensure that the research questions of the project be converted into testable hypotheses, that the performance indicators (PI) to answer those hypotheses are identified, and that proper experimental procedures are developed. This is a complex undertaking, as there are twelve fleets in the project, all of which have different preconditions with respect to data collection possibilities, restrictions on participant recruitment, weather and traffic conditions, etc.

The research questions were divided into the topics of the remaining three work packages of SP4 – WP42 Acceptance; WP43 Behaviour and Side Effects and WP44 Energy Use and Emissions. The hypotheses derived from the research questions are grouped in the same way. The PIs that were identified as necessary for answering the hypotheses are presented in alphabetical order.

Situational variables (SV) are used to describe the surrounding circumstances, which can either be used as covariates that may influence the variable under scrutiny and therefore have to be considered in the computations, or that actually are factors of interest, which can be used as independent variables in certain analyses.

The objectives of WP41 are to draw up general facts relating to hypotheses, experimental design, experimental procedures, etc. This to a large extent coincides with WP31 which focuses on the development of test site specific protocols. Due to this dependency, it was decided to integrate WP41 and WP31, in order for an overall picture be used as a basis while the special requirements that each test site has are already considered from the beginning. The expected results are experimental procedures with one master plan for all fleets, which is adapted to the particularities of each fleet in a way that supports the overall analyses. This means that not all hypotheses will be tested in all fleets, but that comparisons of a number of evaluations can be made between fleets, such that overall evaluations and conclusions will be informed about possible divergences between fleets.

1.1 ecoDriver systems

Two different types of ecoDriver systems exist in principle. One is embedded and can, thus, both receive detailed information from the vehicle and give feedback via vehicle controls. The other is nomadic and has, thus, less information about the vehicle’s state and can give feedback only via the visual or possibly auditory channel.

Within ecoDriver, several realisations of each system type will be produced. While all will be based on the same underlying algorithms for ideal engine usage, they may have different HMIs and feedback strategies and may not make use of all aspects of the algorithms. The three vehicle manufacturers BMW, CRF and Daimler will use an HMI that is in line with their corporate identity. TomTom will use its own interface for its nomadic device. This will most likely also be employed on the bus fleet in the UK. The fleets run by the institutes will use the “generic” embedded ecoDriver system in a number of vehicles, and the “generic” nomadic ecoDriver system in other vehicles.

These differences between systems will, on the one hand, give the possibility to investigate certain aspects that are only typical to one system, in comparison with others who do not have it, but on the other hand it is a challenge to build a sound experimental design to cover all important aspects within the fleets available to the project.

Further detailed descriptions of the systems can be found in ecoDriver Deliverable 11.1 (Hof et al., 2012).

1.2 Open Questions

This deliverable was rescheduled to be finished by M10, i.e. July 2012. During negotiations the duration of WP41 and WP31 was prolonged, however, such that the two WPs now cover the first two years, up to the starting point of the actual trials. This implies that some questions are not solved at the time of writing this deliverable. They are presented and discussed in this deliverable but some decisions will not be able to be made until later on; These decisions will therefore be reported in future deliverables.

1.3 Comparison embedded and nomadic systems

In the Description of Work it is stated that the effectiveness of embedded and nomadic devices will be compared. This has to be taken into account when planning the experiments, but exactly how this will be done has not been decided at the time of writing. Basically, two possibilities exist:

- Between-group comparisons, where the results of a fleet with an embedded device will be compared with the results of a comparable fleet with a nomadic device.
- Within-group comparisons, where the same drivers use both devices.

The former is easier to conduct within the available budget and time frame, but the latter is more reliable when it comes to data interpretation. A combination is also thinkable. Is it envisioned that this question will be solved by a task force within WP41.

1.4 Comparison of the different controlled test sites

As mentioned, ecoDriver will run twelve fleets. These fleets operate in seven different European countries, with different preconditions in terms of traffic, driving culture and climate. For the project it is highly desirable to be able to compare the drivers' behaviour between the fleets, as this would allow for a much more comprehensive data interpretation. Just as with the system comparisons, the exact procedure of how the different sites should be compared will be finalised after the writing of this deliverable.

However, a suggestion has been made, which consists of letting a number of ecoDriver partners drive all controlled routes both with and without the full ecoDriver system active. In order to keep the behaviour as constant as possible across sites the ambition should be to drive as eco-friendly as possible without increased risk taking. This approach would connect the sites by allowing for a number of within-driver analyses. These drivers would come from different countries and, thus, have different driving cultures. By investigating whether possible behavioural changes are systematic across drivers or not, it may be established, or at least give hints whether differences between sites depend on the drivers' culture or on test site features. Obviously, the number of drivers would be rather limited, such that the analyses may have a more qualitative than quantitative character.

There are two main reasons for considering project participants rather than naïve drivers recruited from outside of the project. One is purely economical, as it would incur substantial costs for the project to send drivers to the test sites who do not need to attend project meetings anyway. By scheduling meetings strategically and using drivers who need to be present at most of the meetings anyway, costs can be kept low and within the budget of the project. The second reason is methodological. Drivers recruited especially for the purpose of comparing the test sites, but with no initial knowledge about the system tested, would become more and more familiar with the ecoDriver system over time. This would create results where the factor test site is confounded with the familiarity with the system. If project partners who already are familiar with the system are used, however, this can be avoided. It is envisaged, although not systematically tested, that it is easier to instruct such drivers to respond in a consistent manner to the system instructions, such that the possible variance found can be attributed more easily to differences in the test sites.

The final solution for how the test sites should be compared will be determined by a task force within WP41.

2. Description of Test Site Preconditions

The experiments will be carried out at test sites in seven European countries (France, Germany, Italy, the Netherlands, Spain, Sweden and the United Kingdom). The types and number of vehicles, the available equipment, the traffic and climatic conditions, and a number of other factors set a framework for the experimental design, why this information serves as a basis when formulating the research questions.

The seven test sites are divided into twelve test fleets, where the term test fleet corresponds to the vehicles within a single experiment. The total test fleet includes several different vehicles types. The major part is passenger cars, but there are also trucks, light commercial vehicles (LCV) and a fleet of ten buses. An overview of the vehicles is given in Table 1.

The passenger car fleets cover a wide range of models, from small fuel-efficient cars to large premium cars. The fleets include vehicles with ordinary internal combustion engines (ICE) as well as hybrids and full electric vehicles (FEV) and furthermore, both vehicles with a manual gearbox and vehicles with an automatic gearbox are represented.

Most vehicles are owned by the project partners, with some exceptions. Test fleets 6, 8 and 9 consist of privately owned or company owned vehicles that will be selected at a later stage. The vehicle in test fleet 11 is a long-term rental car and test fleet 12 is owned by a bus fleet operator. In vehicles that are not owned by project partners, there may be some limitations in what kind of equipment that can be installed.

Table 1: Vehicles used in ecoDriver (country abbreviation is brackets refers to test site)

Test fleet #	Vehicles	Model(s)	Propulsion	Gearbox
1 (FR)	10 passenger cars	Renault Clio III	ICE (diesel or petrol)	Manual
2 (FR)	2 passenger cars	Renault Clio III	ICE (petrol)	Manual
3 (DE)	1 passenger car	VW Passat CC	ICE petrol	Automatic (DSG)
4 (DE)	1 passenger car	BMW 5 series	ICE petrol	Automatic
5 (DE)	1 truck	Mercedes-Benz Actros	ICE diesel	Automatic
6 (DE)	10 trucks or LCVs	tbd	tbd	tbd
7 (IT)	4 passenger cars	Fiat 500, Fiat Qubo, Fiat Punto, Lancia Musa	ICE petrol (500, Qubo), ICE diesel (Punto, Musa)	Manual (Fiat 500 robotised manual)
8 (NL)	10 trucks or LCVs	tbd	tbd	tbd
9 (ES)	10 passenger cars	Various models	ICE diesel, hybrid?	tbd
10 (ES)	2 passenger cars	Nissan Leaf, Citroen C0	FEV	Automatic
11 (SE)	1 passenger car	Volvo V70	ICE diesel	Manual
12 (UK)	10 buses	Volvo B5L	Hybrid diesel & electric	Automatic

Table 2 shows type of study, type of ecoDriver system and special research focuses that were suggested by the partners before the actual planning of the experiments began. A naturalistic approach was suggested for five of the test fleets, while a controlled study was preferred in three cases. For the remaining four test fleets, the choice was left open.

Some partners had a specific research interest. The French test site wished to study safety in urban areas and one of the German fleets wanted to focus on driver acceptance. The Swedish partner had an interest in driver distraction and eye tracking. Furthermore, the Spanish test fleets were well suited for the assessment of using an eco-driving system in a hilly landscape, while winter conditions probably could be studied in the Swedish fleet.

A full embedded eco-driving system was suggested as the primary choice for 6–7 of the fleets, while some sort of nomadic device was suggested for the remaining 4–5 fleets. Some of those who preferred the embedded system were willing to include also a nomadic device in their experiments. The nomadic devices available in the study are a TomTom system and an application for Android telephones.

Table 2: Experimental preferences

Test fleet #	Type of study	ecoDriver system	Special focus
1 (FR)	Naturalistic	Nomadic Android	Safety in urban areas
2 (FR)	Controlled	ecoDriver full system or nomadic Android	Safety in urban areas
3 (DE)	Controlled	ecoDriver full system	Driver acceptance
4 (DE)	Controlled	ecoDriver full system	Driver acceptance
5 (DE)	Controlled	ecoDriver full system	-
6 (DE)	Naturalistic	Nomadic aftermarket (TomTom)	-
7 (IT)	Controlled	ecoDriver full system (in two veh.), ecoMove (in two veh.)	-
8 (NL)	Naturalistic	Nomadic aftermarket (TomTom)	-
9 (ES)	Naturalistic	Nomadic	Hilly environment
10 (ES)	Cont./Nat.	ecoDriver full system (one veh.), nomadic (one veh.)	Electric vehicles, hilly environment
11 (SE)	Controlled	ecoDriver full system (+Nomadic Android)	Driver distraction, winter conditions
12 (UK)	Naturalistic	Nomadic Android	Hybrid vehicles

Most vehicles will be equipped with a CAN-logger, except for some of those that will use a nomadic eco-driving system (Table 3). Most of those with logging equipment will also have (front) radar and a video camera. In test fleet 11, an eye tracker will be used in order to enable assessment of driver distraction. In test fleets where a nomadic device is used, the device itself will provide some logging functionality.

Table 3 also shows what – if any – advanced driver assistance systems (ADAS) and built-in energy efficiency system the vehicles have. Most vehicles have some kind of cruise control and some also have more advanced systems that assist the driver in various situations.

Table 3: Equipment

Test fleet #	ADAS	Energy efficiency built-in system	Logging equipment*
1 (FR)	CC, SL	-	CAN-logger?
2 (FR)	CC, SL	-	CAN-logger, radar, video
3 (DE)	ACC, LKA	-	CAN-logger, radar, video
4 (DE)	ACC, LCA, LDW, NV, TSR	BMW Efficient Dynamics	CAN-logger, radar, video
5 (DE)	ABA2, ACC, LDW	-	CAN-logger, radar, video
6 (DE)	tbd	tbd	tbd
7 (IT)	CC (in Musa)	Fiat ECO drive (in 500)	CAN-logger
8 (NL)	tbd	tbd	tbd
9 (ES)	tbd	tbd	CAN-logger
10 (ES)	-	Standard FEV system	CAN-logger, radar (only in one veh.), video (only in one veh.)
11 (SE)	ACC, BLIS, FCA	-	CAN-logger, video, eye tracker
12 (UK)	-	Hybrid system information	-

(*) In addition to the logging capabilities of the ecoDriver system

Table 4 shows the number of drivers that were suggested to be recruited to each test fleet. The suggestions were proposed by individual partners involved in the trials based on resources available to them. The numbers are approximate and should merely be seen as a hint of the size of the experiments. The final number of drivers will be determined by the experimental design.

Some partners have preferences regarding driver selection criteria, which also are shown in Table 4. In particular, some will only be able to recruit drivers among employees, which may put some limitations on the type of drivers that are possible to include in the experiments. The test sites have different characteristics when it comes to traffic density, type of landscape and climate, Table 5. These factors will potentially have an influence on eco-driving behaviour and fuel consumption and hence, they are important to consider when designing the experiments. Particularly the traffic density varies a lot across the test sites, which allows for a wide range of test scenarios regarding eco-driving behaviour. The landscape is flat or moderately hilly at most test sites, with the exception for the Spanish test site, which is located in a hilly area. The test sites also cover a wide spectrum of climatic conditions that can have an influence on energy consumption. For example, in Northern Europe, it will be possible to study the influence from cold weather, and in hot temperatures in Southern Europe the effects from using (or over-using) air condition can be assessed. Regarding type of routes, most test sites are located in areas where both urban and rural roads as well as motorways are present. For all test fleets except for fleet 12, the routes can be chosen relatively freely. Fleet 12 consist of buses that operate along certain routes.

Table 4: Drivers

Test fleet #	Approx. # of drivers	Predefined selection criteria
1 (FR)	10	Non-professional drivers without any eco-driving experience
2 (FR)	20	Non-professional drivers without any eco-driving experience
3 (DE)	>10	Non-professional young male drivers
4 (DE)	>10	BMW employees
5 (DE)	10	Daimler employees
6 (DE)	>10	Professional truck/LCV drivers
7 (IT)	10	Non-professional CRF employees, 30–55 years of age
8 (NL)	>10	Professional truck/LCV drivers
9 (ES)	10	Non-professional drivers without any eco-driving experience
10 (ES)	24	CTAG employees
11 (SE)	10	Non-professional drivers recruited from the general public
12 (UK)	30	Professional bus drivers employed by the fleet operator

Table 5: Traffic conditions and climate

Test fleet #	Traffic density	Routes	Landscape	Climate
1 (FR)	Low to congestion	All	Flat, hilly	Western/Atlantic European
2 (FR)	Low to congestion	All	Flat, hilly	Western/Atlantic European
3 (DE)	Low	Motorway, urban	Flat	Central European
4 (DE)	High	All	Flat	Central European
5 (DE)	High	All	Mostly flat	Central European
6 (DE)	Low to congestion	All	Mostly flat	Central European
7 (IT)	Low to congestion	All	Flat, hilly	Mediterranean
8 (NL)	Low to congestion	All	Mostly flat	Western/Atlantic European
9 (ES)	Low to high	All	Hilly	Western/Atlantic European
10 (ES)	Low to high	All	Hilly	Western/Atlantic European
11 (SE)	Low to moderate	All	Mostly flat	Scandinavian
12 (UK)	Low to high	Urban	Flat, hilly	Western/Atlantic European

3. Research Questions

According to the Description of Work (ecoDriver consortium, 2011), the detailed aims of ecoDriver are to:

1. Investigate how best to win the support of the driver to obtain the most energy-efficient driving style for best energy use, covering preview, the current situation and post-drive feedback and learning.
2. Assess this across a wide range of vehicles — e.g., cars, vans, light and heavy trucks and buses – covering both individual and collective transport.
3. Explore and evaluate alternative HMIs and styles of feedback.

4. Consider driver behaviour with a wide range of current and future powertrains, including internal combustion (both petrol and diesel), hybrid and electric, and provide the optimum advice for each powertrain.
5. Consider driver style, driver learning and consider how the systems can affect driving style
6. Look at the impacts of eco-driving support on driver attention and safety.
7. Look at a variety of impacts: CO_2, NOx, particulates, etc. And the balance between impacts
8. Consider how the observed effects on driving style would affect network-wide energy use and a variety of aspects of network performance including network efficiency.
9. Consider scenarios for future powertrain adoption, and how eco-driving might affect the road networks of the future.
10. Perform a cost benefit analysis considering a range of scenarios of powertrain adoption.

The specific measurable objectives of ecoDriver are to:

1. Optimise feedback to drivers for both nomadic devices and built-in systems and compare the effectiveness of each (measured by reduced energy consumption as compared with an existing baseline system). This will be assessed both in SP2 and in SP4.
2. Improve driver acceptance including by adapting feedback style to a variety of drivers (measured by higher acceptance on subjective questionnaires to be collected in SP1 and SP3).
3. Minimise any side-effects of eco-driving support in terms of impacts on driver attention and safety (measured by visual allocation and other indicators of attention as measured in the experimental work in SP1 and the evaluation conducted in SP4).
4. Use optimised real-time fuel use models so that the feedback to drivers is as accurate as possible (measured by calibration with off-line models in SP2).
5. Achieve a sustained 20% reduction in energy use (measured in real-world driving across a range of vehicles, assessed in SP4 and further extrapolated in SP5).

The aim of SP4 is to carry out a comprehensive evaluation of the field trials conducted in SP3. This evaluation will cover a subpart of the aims listed above, namely those related to energy efficiency, acceptance, driving behaviour and safety.

The fundamental research question of ecoDriver is "*Do the solutions proposed by ecoDriver reduce energy consumption?*" In addition, there are – as mentioned above – a number of research questions on emissions, acceptance and behaviour that should be addressed in SP4. In the Description of Work (ecoDriver consortium, 2011), the following research questions have been formulated:

- Are the solutions accepted by the users?
- Are there any important trade-offs between the benefits in terms of energy use and increases in harmful emissions?
- How does adopting an eco style of driving affect the safety of driving?
- Are there any negative side-effects of the solutions, e.g., in terms of driver distraction?
- Does compliance with ecoDriver advice result in any problematic interactions with other, non-equipped traffic?
- Does acceptance and compliance vary by usage context (private or fleet, etc)?

- Does compliance and acceptance change over time?

Another central objective of SP4 is to provide a deeper insight into how ecoDriver advices influence driving behaviour, since it will be useful for further improvements of the system.

The high-level research questions were divided into three groups: 1) Energy use and emissions, 2) Behaviour and side effects, and 3) Acceptance. The first one covers the direct aims of a support system for eco-driving, that is, the reduction of energy consumption and dangerous emissions.

However, these should not be achieved at any cost, but only when traffic safety is not negatively affected. While it can be assumed that fuel efficient driving and safe driving often are congruent with each other, it is also possible to imagine scenarios where this is not the case. A driver may for example show reluctance to reduce speed when passing a zebra crossing or when approaching an amber traffic light, running the risk of violating a pedestrian's right of way, or running a red light. Also, a support system with a visual component is bound to attract the driver's visual attention, which can be hazardous to safe driving. Furthermore, behavioural adaptations may have effects in the interaction with others, causing changes on a traffic system level. Therefore, a thorough assessment of possible side effects and behavioural adaptations was deemed to be necessary, such that we will be able to make a confident assessment about the effects that the ecoDriver system will have on driving behaviour, traffic safety and traffic flow.

Of course the best technical system can only have an effect if it is used, therefore it is very important to create a system that will be accepted by the end users. Acceptance can be measured subjectively, by asking the users about their opinion, or objectively, by monitoring how much and in which situations the system is used.

The high-level research questions that are presented below were developed based on a combination of the general aims of ecoDriver and discussions that took place both during the formulation of the description of work, and during dedicated meetings in WP41.

3.1 Energy Use and Emissions

The research questions on energy use and emissions are:

E1: Do the solutions proposed by ecoDriver reduce energy consumption?

E2: Are there any important trade-offs between the benefits in terms of energy use and increases in harmful emissions?

3.2 Behaviour and Side Effects

The research questions on driver behaviour and side effects are:

B1: How does ecoDriver advice influence driving behaviour?

B2: How does adopting an eco style of driving affect the safety of driving?

B3: Are there any negative side-effects of the solutions, e.g., in terms of driver distraction?

B4: Does compliance with ecoDriver advice result in any problematic interactions with other, non-equipped traffic?

3.3 Acceptance

The research questions on acceptance are:

A1: Are the solutions accepted by the users?

A2: Does acceptance and compliance vary by usage context (private or fleet, etc)?

A3: Does acceptance and compliance change over time?

A separate work package (WP42) deals with the development and selection of acceptance related questions and issues, such that the topic is dealt with here only in a cursory fashion.

4. From Research Questions to Hypotheses, Performance Indicators and Sensors

While the research questions give the high level goals, it is necessary to develop testable hypotheses as well. In the FESTA project a framework was developed that provides a structure how to go from high-level research questions down to testable hypotheses with appropriate performance indicators (PIs), measures and sensors (FESTA Consortium). It was decided to use this structure as a recipe for the formulation of hypotheses for the ecoDriver project. At the same time it is necessary to be pragmatic, as it is already known from the start that certain measures will not be accessible within the given setting. Emissions, for example cannot be measured directly without very expensive equipment, so it is clear that they need to be assessed via an emissions model. Therefore, when formulating the hypotheses we balanced the ideal set of hypotheses against what was actually estimated to be measurable realistically.

4.1 Hypotheses

The hypotheses are closely related to the research questions and thus, three work groups – corresponding to the three groups of research questions – were formed, containing members of WP41. The work group members are experts in the respective field of research. Each group made a first draft of hypotheses related to the respective research questions, which then provided a basis for a workshop held in Hoofddorp in the Netherlands in the beginning of 2012. The hypotheses were generated in local brain storming sessions, with following discussions both on a local level and within the whole group via a telephone conference. In the workshop the hypotheses were discussed and reviewed by the work group members, with the aim of ending up with a list of relevant hypotheses that are testable and applicable with the test site preconditions in mind.

The hypothesis generation resulted in a relatively large number of hypotheses. It is not intended that all hypotheses should be tested by all test fleets and all hypotheses are not even testable in all fleets. Instead, the hypotheses will be matched to and distributed among the test fleets (see also Chapter). Fundamental hypotheses that are relatively easy to test will be tested by all or almost all test fleets, while less important or resource demanding hypotheses will be tested by only a few fleets. Those hypotheses that were considered to be impossible to test due to either budget restrictions, technological limitations or other issues were rejected. Again, these decisions were made by expert groups after careful consideration of the options. An excel file was created (Annex C), which contains the included and excluded hypotheses.

A number of hypotheses, especially those concerned with interface design, were considered to be suitable to be tested during the simulator trials, such that interface that would eventually be used in the field trials was as good as possible. These hypotheses were handed over to SP1, where they were treated further. The hypotheses presented here are those that are carried forward all the way to the field trials.

At the time of the hypothesis generation, the ecoDriver systems were not yet designed and implemented. As a consequence, some hypotheses may need to be modified when the system design is finalized, in order to be relevant or testable. Furthermore, there may be a need of adding some hypotheses related to the type of feedback and the HMI. The extension of WP41 and the close collaboration with WP31 as well as the other WPs in SP3 guaranteed that this part of the work would be seen through. It can be added that an SP3/SP4 task force was created when WP41 drew to a close, in order to carry the work forward and to close the gap between the more theoretical preparatory work done in WP41, and the actual implementation of all the sensors in the vehicles, with all the real world constraints encountered in SP3. The task force held a workshop in the end of 2013, to make sure that the all the relevant aspects of the actual ecoDriver application were covered in the hypotheses, like a comparison between the nomadic and the embedded implementation of the application.

WP41 advocates that data analysis should not be done by VMC, but across VMCs by hypothesis, always taking into account as many data points as possible. Thus, possible interaction effects that can be due to the test site may be uncovered and possibly explained, while the results that hold true across several sites can be viewed as more general and stronger.

The tables below aim at providing descriptions of all hypotheses, to explain why and how they should be tested and to give some guidelines on how to use and interpret the results.

4.1.1 Energy Use and Emissions

The main hypotheses related to energy use and emissions and relatively straight forward, but a wide range of systems characteristics can influence these emissions. Some hypotheses are related to a pure environmental vision, while others depend on system types. There may be a need to adapt the following hypotheses (or add new ones) depending on the final version of systems HMI. Some of the hypotheses relate to the so-called "golden rules of eco-driving", as discussed by the International

Commission for Driver Testing Authorities (CIECA, 2007; see also Barkenbus, 2010; Beusen et al, 2009).

Using ecoDriver system will reduce the average Greenhouse effect gas (GEG) emissions	
Research question(s):	E1, E2
Motivation:	ecoDriver system should help reducing the greenhouse effect gas (GEG) emissions
Performance indicator(s):	Grams of NOx per 100km (4.2.4) Grams of CO per 100km (4.2.4) Grams of PM10 per km (4.2.4)
Type of experiment:	Controlled and naturalistic experiments
Comparison:	System vs. baseline. Full system vs. nomadic.
Meaning and impact:	GEG emissions can be different from fuel consumption as some gas is emitted in specific circumstances that depends on driving strategies (accelerations mainly).
Pitfalls:	Real data measured from CAN or other sensors will need to be sent to TNO for Versit+ model. This may induce additional delays.

Using ecoDriver system will reduce the average energy consumption	
Research question(s):	E1, E2
Motivation:	ecoDriver system should help reducing the fuel consumption and so the energy used
Performance indicator(s):	Fuel litres per 100km (4.2.6) Mega joules per 100km (4.2.6) Grams of CO2 per km (4.2.6)
Type of experiment:	Controlled and naturalistic experiments
Comparison:	System vs. baseline. Full system vs. nomadic.
Meaning and impact:	The main goal of the ecoDriver device is to reduce fuel consumption. It is mandatory to study the real impact of the system once build.
Pitfalls:	Fuel consumption is obtained as a cumulative value on CAN buses and additional data treatments will be needed. Energy consumption may be difficult to measure for EV or HEV.

Using ecoDriver system will keep constant (or increase) the energy savings over time	
Research question(s):	E2
Motivation:	ecoDriver system should help reducing the GEG emissions and should help the drivers maintaining their improvements over time.
Performance indicator(s):	Fuel litres per 100km (4.2.6) Mega joules per 100km (4.2.6) Grams of CO2 per km (4.2.6)
Type of experiment:	Controlled
Comparison:	Average fuel consumption for successive trips. (Trip 1 vs. Trip 2 vs. ... vs. Trip N).
Meaning and impact:	The goal is to check the efficiency of the system over time, and to study if some misuses appear that could impact long term fuel savings.
Pitfalls:	Subjects will drive the same trip 10 times and will therefore improve the knowledge of the roads travelled. This will induce a small positive bias on energy consumption over time.

4.1.2 Behaviour and Side Effects

The behaviour and side effects category covers a wide range of behavioural aspects, from workload to safety to changes in driving style. Therefore, the hypotheses were grouped into three subcategories:

- **Workload and distraction:** Any type of information or tasks that require attention or actions from the driver might increase workload. Furthermore, there is a risk that the ecoDriver system increases visual distraction. Increased workload and distraction might or might not be disadvantageous for safety, which is why such hypotheses are relevant to test.
- **Driving behaviour and safety:** These hypotheses investigate whether there are any negative side-effects or safety related issues associated with the use of an ecoDriver system. These hypotheses also cover potential positive effects.
- **Eco-driving behaviour:** These hypotheses are important in order to understand how ecoDriver advice influences driving style.

The idea of introducing eco-driving systems is that under most conditions drivers should be able to handle additional information without compromising safety. Therefore, it can be said that a "ceiling effect" – the added task of considering the eco-driving advice – has no measurable effect on safety. However, there may still be a measurable effect on behaviour, and the difficult task for the researcher is to separate the effect on behaviour from the effect on safety.

Workload and distraction: The workload of the driver will increase when (s)he has an ecoDriver system that gives in-car feedback.	
Research question(s):	B2, B3
Motivation:	Increased workload may be disadvantageous from a safety perspective.
Performance indicator(s):	NASA-TLX (4.2.16)
Type of experiment:	Simulator tests and controlled field tests, since it may be too complicated to get the measures needed in naturalistic tests.
Comparison:	System vs. baseline.
Meaning and impact:	If workload is found to be too high, the system needs to be modified.
Pitfalls:	Workload may decrease when the driver get used to the system and adapt to an eco driving style. The hypothesis should thus be tested for short-term use as well as for long-term use. It should be noted that workload doesn't vary monotonously with safety effects. There is rather a curvilinear relationship, where neither overload nor under load is beneficial for safety. In FEVs, workload may decrease if the driver experiences less "range anxiety".

Workload and distraction: The driver is more distracted (eyes more "off the road") with an ecoDriver system that gives in-car feedback.	
Research question(s):	B2, B3
Motivation:	When the driver is intermittently interrupted by the ecoDriver system (s)he will spend more time scanning the instrument panel, the display of the ecoDriver system (if any), instead of paying full attention to the surrounding traffic environment.
Performance indicator(s):	AttenD (4.2.2) Percentage Road Centre (4.2.14)
Type of experiment:	Simulator tests and controlled field tests. Visual behaviour is strongly influenced by the context, why this hypothesis is most suitable for controlled tests.
Comparison:	Real-time feedback vs. post-trip feedback. System (real-time feedback) vs. baseline.
Meaning and impact:	If the system is visually distracting it needs to be modified.
Pitfalls:	Improved scanning behaviour in order to plan ahead for future events might increase the eyes-off-road time while still being beneficial for traffic safety.

Workload and distraction: In-car feedback from the ecoDriver system cause inappropriate/dangerous visual behaviour, in terms of glances towards the device	
Research question(s):	B2, B3
Motivation:	An ecoDriver system with visual feedback that triggers the driver to look away from the traffic in inappropriate situations such as when entering an intersection or when driving over the crest of a hill is undesirable.
Performance indicator(s):	Visual Demand Metric (4.2.13) Glance Statistics (4.2.7)
Type of experiment:	Simulator tests and controlled field tests. Visual behaviour is strongly influenced by the context, why this hypothesis is most suitable for controlled tests.
Comparison:	Real-time feedback vs. post-trip feedback. System (real-time feedback) vs. baseline.
Meaning and impact:	If the system is visually distracting it needs to be modified.
Pitfalls:	Glances towards the device require that there is a device to look at. Consequently this hypothesis is only valid for ecoDriver systems with visual feedback. Comparison with baseline requires that there is a device to look at during baseline. To overcome this issue it is possible to compare glance statistics with the thresholds that are defined in various driver distraction guidelines (NHTSA, AAM, etc.).

Workload and distraction: The driver will look more at the speedometer/rev counter when using the ecoDriver system	
Research question(s):	B2, B3
Motivation:	In order to drive more eco-friendly, the driver will start monitoring the speedometer/rev counter more carefully.
Performance indicator(s):	Glance Statistics (4.2.7)
Type of experiment:	Simulator tests and controlled field tests. Visual behaviour is strongly influenced by the context, why this hypothesis is most suitable for controlled tests.
Comparison:	System (all types of feedback) vs. baseline
Meaning and impact:	If the driver is spending too much time looking at the speedometer/rev counter at the expense of visual scanning of the road ahead, the ecoDriver system needs to be modified.
Pitfalls:	Glances towards the speedometer/rev counter may decrease when the driver get used to the system and learns the eco driving style by heart. The hypothesis should thus be tested for short-term use as well as for long-term use.

Workload and distraction: There will be more visual distraction with nomadic devices (smart phones with small screens) than with an embedded system	
Research question(s):	B2, B3
Motivation:	Guidelines dictate minimum requirements on how an embedded system should behave. This includes where the device/screen is positioned, where manual controls are located etc. Such guidelines are not available to nomadic devices, and as a result, the interfaces on such devices are usually less suited for use while driving.
Performance indicator(s):	Visual Demand Metric (4.2.13) Glance Statistics (4.2.7) AttenD (4.2.2)
Type of experiment:	Simulator tests and controlled field tests. Visual behaviour is strongly influenced by the context, why this hypothesis is most suitable for controlled tests.
Comparison:	Nomadic vs. embedded
Meaning and impact:	The results will provide insight in the question whether traffic safety is compromised by using nomadic devices (compared to nomadic devices) for the ecoDriver application.
Pitfalls:	The position of the nomadic device in the vehicle is of importance.

Driving behaviour and safety: Mean speed will be equal or lower when using an ecoDriver system	
Research question(s):	B1, B2
Motivation:	The relationship between speed and fuel consumption is not straightforward and it is dependent on the design of the motor. Usually, the fuel consumption per distance travelled for ICEs is the lowest when speed is in the range of 60–90 km/h. Therefore, when driving at higher speeds, the ecoDriver system can be expected to encourage the driver not to exceed speed limits, or even to drive slower than the speed limit dictates. Electrical vehicles and hybrid vehicles are assumed to be the most fuel efficient at even lower speeds. Some further information on the relationship between fuel consumption and speed is given by (Hof, et al., 2012; WisDOT, 2011; ECN, 2012).
Performance indicator(s):	Mean speed (4.2.11)
Type of experiment:	Controlled and naturalistic.
Comparison:	System vs. baseline.
Meaning and impact:	The analysis will report on a speed reduction from what initial speed to what new speed the effect goes. The results will also provide some insights into if and how the ecoDriver system influences driving behaviour.
Pitfalls:	For ICE vehicles, the engine is the most efficient at approximately 60–90 km/h, why this hypothesis isn't valid for very low speeds.

Driving behaviour and safety: Speed will be higher when driving through/past locations were a low speed is recommended when using an ecoDriver system	
Research question(s):	B1, B2, B3, B4
Motivation:	Maintaining a steady speed is one of the fundamental rules of eco-driving. Thus, there is a risk that drivers do not lower the speed to the same extent with the system as without the system, when driving past locations were a low speed is recommended. Five such locations/situations have been identified: - Intersections without traffic lights - Zebra crossings - Speed reducing measures - Corners/sharp curves - Villages
Performance indicator(s):	Mean speed (4.2.11) Instantaneous speed (4.2.11) Speed profile (4.2.11)
Type of experiment:	Controlled and naturalistic.
Comparison:	System vs. baseline.
Meaning and impact:	If the hypothesis is accepted, it might imply that there is a safety risk associated with the ecoDriver system. In that case, the impact of the higher speed should be analysed, and if it is concluded that it has a negative effect on safety, some recommendations on modifications of the ecoDriver system should be suggested. The results will also provide some insights into if and how the ecoDriver system influences driving behaviour.
Pitfalls:	based on continues driving

Driving behaviour and safety: There will be more occasions of speeding when driving downhill when using an ecoDriver system	
Research question(s):	B1, B2, B3
Motivation:	Braking wastes fuel and there is thus a risk that drivers avoid braking in (steep) downhill slopes.
Performance indicator(s):	Percentage speeding (4.2.11) Speeding speed (4.2.11)
Type of experiment:	Controlled and naturalistic. Probably most suitable for controlled studies were the characteristics of the slopes are known.
Comparison:	System vs. baseline.
Meaning and impact:	If speed increases to safety critical or illegal levels, some recommendations on modifications of the ecoDriver system should be suggested. The results will also provide some insights into if and how the ecoDriver system influences driving behaviour.
Pitfalls:	The hypothesis is only relevant for steep slopes that will cause the vehicle to accelerate.

Driving behaviour and safety: There will be fewer occurrences where the vehicle in front is in the driver's safety zone when using an ecoDriver system	
Research question(s):	B1, B2
Motivation:	Anticipating the traffic situation and avoiding unnecessary braking will save fuel. From an eco-driving perspective, it will thus be beneficial to keep track of surrounding traffic and consequently conflicts may be avoided.
Performance indicator(s):	Range over range rate (4.2.10)
Type of experiment:	Controlled and naturalistic.
Comparison:	System vs. baseline.
Meaning and impact:	Fewer occurrences where the vehicle in front is in the driver's safety zone will be beneficial for safety. The results will also provide some insights into if and how the ecoDriver system influences driving behaviour.
Pitfalls:	Traffic density will probably have an influence on the distance to the vehicle in front, why this needs to be considered when testing and interpreting the hypothesis. Since braking will not save fuel, drivers may use their brakes as little as possible. This may lead to more occasions where surrounding traffic is in the drivers comfort zone (since the driver is avoiding using the brakes).

Driving behaviour and safety: There will be shorter distances to following vehicles in/during safety critical locations/situations when using an ecoDriver system	
Research question(s):	B2, B3, B4
Motivation:	Anticipating the traffic situation and avoid unnecessary braking will save fuel. This implies that it is beneficial to decelerate smoothly when entering safety critical locations/situations such as intersections, traffic lights, corners and slower vehicles. As a consequence, the distance to following vehicles that do not apply eco-driving principles may decrease.
Performance indicator(s):	Distance headway (4.2.8) Time headway (4.2.8)
Type of experiment:	Controlled and naturalistic.
Comparison:	System vs. baseline.
Meaning and impact:	A decreased distance to following vehicles may increase the risk of rear-end collisions. A way of evaluating the impact of a decreased distance is to compare the results with the corresponding stopping distance.
Pitfalls:	Traffic density will probably have an influence on the distance to the following vehicle, why this needs to be considered when testing and interpreting the hypothesis.

Driving behaviour and safety: There will be more red or amber light violations when using an ecoDriver system	
Research question(s):	B2, B3, B4
Motivation:	Braking and stopping waste fuel and thus, there is a risk that drivers are tempted to violate red or amber light.
Performance indicator(s):	Number of red/amber light violations per 100 km (4.2.12)
Type of experiment:	Naturalistic. Not feasible for controlled tests since the drivers often will be accompanied by an observer which may influence the drivers willingness to violate red/amber lights.
Comparison:	System vs. baseline.
Meaning and impact:	Violating red or amber light is clearly a safety risk. If the hypothesis is accepted, some recommendations on modifications of the ecoDriver system should be suggested.
Pitfalls:	Red/amber light violations can be expected to occur relatively rarely. Much data are thus needed in order to get reliable results.

Driving behaviour and safety: There will be fewer overtaking when using an ecoDriver system	
Research question(s):	B1, B2
Motivation:	Maintaining a steady speed and avoid accelerations is beneficial from an eco-driving perspective. Furthermore, when driving at higher speeds an increase in speed will lead to higher fuel consumption per distance driven. Thus, in order to drive fuel efficient, overtaking should in most cases be avoided.
Performance indicator(s):	Number of overtaking per 100 km (4.2.9)
Type of experiment:	Controlled and naturalistic.
Comparison:	System vs. baseline.
Meaning and impact:	Fewer overtaking will be beneficial from a safety perspective.
Pitfalls:	Traffic and road type dependencies to be expected?

Eco-driving behaviour: The average rpm when shifting up will be reduced when using an ecoDriver system	
Research question(s):	B1
Motivation:	This hypothesis is related to the golden rule of eco-driving #1: *Shift up as soon as possible: Shift up between 2.000 and 2.500 revolutions per minute.* Applies only to vehicles with manual gearbox.
Performance indicator(s):	Average rpm when shifting gear up (4.2.15)
Type of experiment:	Controlled and naturalistic.
Comparison:	System vs. baseline.
Meaning and impact:	The results will provide knowledge on if and how the ecoDriver system influences the driving style.
Pitfalls:	

Eco-driving behaviour: The weighted average engine rpm will be decreased when using an ecoDriver system	
Research question(s):	B1
Motivation:	This hypothesis is related to the golden rule of eco-driving #2: *Maintain a steady speed. Use the highest gear possible and drive with low engine rpm.*
Performance indicator(s):	Weighted average engine rpm (4.2.15)
Type of experiment:	Controlled and naturalistic.
Comparison:	System vs. baseline.
Meaning and impact:	The results will provide knowledge on if and how the ecoDriver system influences the driving style.
Pitfalls:	

Eco-driving behaviour: Driving will be more smooth when using an ecoDriver system	
Research question(s):	B1
Motivation:	This hypothesis is related to the golden rule of eco-driving #3: *Anticipate traffic flow: Look ahead as far as possible and anticipate the surrounding traffic.* A smooth driving pattern is obtained by a moderate gas pedal pressure, a steady speed and smooth decelerations. The hypothesis can be divided into 5 sub hypotheses: - The variability of speed profiles will be decreased when using an ecoDriver system - The number of strong accelerations will be reduced when using an ecoDriver system - The number of hard decelerations will be reduced when using an ecoDriver system - Acceleration in general will be smoother when using the ecoDriver system - Deceleration in general will be smoother when using the ecoDriver system
Performance indicator(s):	Positive kinetic energy (4.2.11) Standard deviation of speed (4.2.11) Spectral arc length of speed (4.2.11) Mean maximum accelerations above threshold (4.2.1) Mean maximum decelerations above threshold (4.2.1) Number of accelerations above threshold (4.2.1) Number of decelerations above threshold (4.2.1)
Type of experiment:	Controlled and naturalistic.
Comparison:	System vs. baseline.
Meaning and impact:	The results will provide knowledge on if and how the ecoDriver system influences the driving style.
Pitfalls:	The choice of gas pedal pressure and acceleration is not straightforward, and it depends on speed as well as engine design and driveline design and vehicle mass. Some eco-driving rules advocate a moderate gas pedal pressure, while other recommends a swift acceleration to cruising speed. There are also eco-driving rules that don't mention gas pedal pressure and acceleration at all. Therefore, the advice from the specific ecoDriver system and the properties of the specific engine must be kept in mind when analysing and interpreting the results. For ICEs, smooth accelerations contributes to reach the best efficiency for vehicles that are very efficient over a wide range of RPM, while quicker acceleration profiles are needed for vehicles that are highly efficient over only a narrow range of RPM (Hof, et al., 2012). It is suggested to separate between high speed and low speed when analysing accelerations. When driving at low speeds, swift acceleration to a better operating point may be beneficial.

Eco-driving behaviour: The usage of the engine brake will be improved when using an ecoDriver system	
Research question(s):	B1
Motivation:	This hypothesis is related to the golden rule of eco-driving #4: *When you have to slow down or to stop, decelerate smoothly by releasing the accelerator in time, leaving the car in gear.*
Performance indicator(s):	Percentage of engine brake (4.2.5) Percentage of what, with respect to what?
Type of experiment:	Controlled and naturalistic.
Comparison:	System vs. baseline.
Meaning and impact:	The results will provide knowledge on if and how the ecoDriver system influences the driving style.
Pitfalls:	The hypothesis applies to vehicles with a manual as well as an automatic gearbox, but the effect of the engine brake may differ somewhat between different gearboxes. In vehicles with a manual gearbox, the driver can select gear and thus influence the deceleration rate. In vehicles with automatic gearbox, the vehicle selects gear and in some cases the engine brake may be weak (however, in some vehicles with an automatic gearbox, the driver can actually change gears). As a consequence, vehicles with automatic gearboxes should be analysed separately.

Eco-driving behaviour: Acceleration after standing still will be more aggressive when using an ecoDriver system	
Research question(s):	B1, B2, B3
Motivation:	Driving at very low speeds is inefficient, particularly for ICEs. It may thus be beneficial to accelerate swiftly from idling to cruising speed.
Performance indicator(s):	Max acceleration (4.2.1)
Type of experiment:	Controlled and naturalistic.
Comparison:	System vs. baseline.
Meaning and impact:	The results will provide knowledge on if and how the ecoDriver system influences the driving style.
Pitfalls:	The choice of gas pedal pressure and acceleration is not straightforward, and it depends on speed as well as engine design. Some eco-driving rules advocate a moderate gas pedal pressure, while other recommends a swift acceleration to cruising speed. There are also eco-driving rules that don't mention gas pedal pressure and acceleration at all. Therefore, the advice from the specific ecoDriver system and the properties of the specific engine must be kept in mind when analysing and interpreting the results. For ICEs, smooth accelerations contributes to reach the best efficiency for vehicles that are very efficient over a wide range of RPM, while quicker acceleration profiles are needed for vehicles that are highly efficient over only a narrow range of RPM. For hybrids and FEVs, a smooth acceleration is recommended in general. (Hof, et al., 2012)

Eco-driving behaviour: Deceleration when entering safety critical locations/situations will be less aggressive when using an ecoDriver system	
Research question(s):	B1, B2
Motivation:	Anticipating upcoming situations that requires a lower speed and slowing down without using the brake saves fuel. The deceleration pattern in these situations can thus be expected to be smoother with the system than without. Examples of safety critical locations and situations are intersections, traffic lights, corners and slow vehicles. Schools, old people's homes etc. can also be added as low speed zones, as long as they are available on maps. A coupling to time of day can also be considered.
Performance indicator(s):	Maximum deceleration (4.2.1) Maximum jerk (4.2.1)
Type of experiment:	Controlled and naturalistic.
Comparison:	System vs. baseline.
Meaning and impact:	A smoother deceleration pattern is probably beneficial from a safety perspective. Anticipating upcoming situations probably implies that the driver is more attentive, which is positive. There is however a risk that a change in deceleration pattern means that the adaptation to traffic flow worsens and that the speed when driving through/past the safety critical locations/situations is higher. This will be tested by other hypotheses. The results will also provide some insights into if and how the ecoDriver system influences driving behaviour.
Pitfalls:	Safety critical locations/situations refer in this case to locations and situations that can be foreseen. It does not include sudden events that require an immediate response, such as a pedestrian unexpectedly crossing the road.

Eco-driving behaviour: The use of speed assistance systems will increase when using an ecoDriver system	
Research question(s):	B1
Motivation:	Maintaining a steady speed and anticipating the traffic flow will save fuel. It can thus be expected that drivers will use speed assistance systems more frequently. Three types of speed assistance systems will be investigated: - Adaptive cruise control - Cruise control - Speed limiter
Performance indicator(s):	Percentage of time/distance with system active (4.2.3)
Type of experiment:	Naturalistic.
Comparison:	System vs. baseline.
Meaning and impact:	The results will provide knowledge on if and how the ecoDriver system influences the driving style.
Pitfalls:	Using cruise control systems in hilly landscapes might not be beneficial from an eco-driving perspective. When going uphill, the system will keep the pre-set speed which consumes a lot of energy.

Eco-driving behaviour:	***Hypotheses related to the type of feedback and the HMI***
Research question(s):	B1, B2, B3, B4
Motivation:	At the time of hypothesis generation, the ecoDriver systems that were to be used in the experiments were not yet developed. Thus, hypotheses on driving behaviour related to the type of feedback and the HMI could not be formulated. It is therefore suggested that such hypotheses are considered when the ecoDriver systems are available. Some examples: - The frequency with which the ecoDriver system presents information decreases over time - Compliance is high for advice X (measured by driver actions) - Haptic feedback gives lower speeds than visual feedback - Comparison of full system and nomadic system It should be noted that the main part of the evaluation of different feedback and HMI solutions will be done in the simulator studies in SP1. Feedback and HMI aspects will also be covered by the acceptance hypotheses.
Pitfalls:	Time may be an important factor for these hypotheses (short-term vs. long-term effects).

4.1.3 Acceptance

Hypotheses and performance indicators related to acceptance will be handled in work package 42 and presented in deliverable D42.1 *Performance indicators and acceptance analysis of the ecoDriver design*. Some acceptance measures are planned to be recorded on-line (while driving) in the controlled studies, such that there is potential to set the results in direct relation to differing traffic situations. Of course, the occurrence of these situations can only be planned to a certain extent.

4.2 Performance Indicators

This section contains definitions and descriptions of the performance indicators (PI).

Definition: PIs are quantitative or qualitative measurements, agreed on beforehand, expressed as a percentage, index, rate or other value, which is monitored at regular or irregular intervals and can be compared with one or more criteria.

The aim is to provide some general instructions on how the various PIs should be calculated and also to give some guidelines on how the PIs should be used and applied when testing a certain hypothesis. It is however not possible to give detailed instructions on, e.g., how to filter and pre-process the raw data, how to aggregate the data or what situational variables (SV) to use, since that will depend a lot on the experimental setting and the sensors, which will be different at different test sites .

The situational variables that are listed for each hypothesis/PI should be seen as suggestions. It may be justified to use other and/or more SVs, but it is recommended to not divide the data into too many SVs, since that will decrease power and increase the complexity of the analysis. Indicators that use the same measures or that are calculated in a similar way have been grouped.

Some of the proposed PIs, such as speed and workload based PIs, are rather general and are applicable in various types of driving behaviour studies. Another category of PIs are those related to fuel consumption, which are fairly simple and straightforward as long as all needed information is available. When it comes to eco-driving specific hypotheses, there is no established standard set of PIs defined. There are a few publications on eco-driving where some PIs have been suggested, such as average shifting point, brake and gas pedal push, percentage time heavy accelerations and relative positive accelerations (Beusen et al., 2009; Larsson and Ericsson, 2009; Gonder et al., 2011; Dogan et al. 2011). The eco-driving related PIs presented below are partly based on the ones found in the literature and partly tailor-made for the purposes of ecoDriver.

4.2.1 Acceleration and deceleration

- Mean maximum accelerations above threshold [m/s^2]
- Mean maximum decelerations above threshold [m/s^2]
- Maximum acceleration [m/s^2]
- Maximum deceleration [m/s^2]
- Maximum jerk [m/s^3]
- Number of accelerations above threshold [-]
- Number of decelerations above threshold [-]

Description

This category considers longitudinal accelerations and decelerations. The terminology used here is that acceleration corresponds to increases in speed while deceleration corresponds to decreases in speed. Both quantities are given as positive numbers in the range of 0 to infinity. (The physical quantity acceleration is defined as change in speed, and this includes both positive and negative values, where the latter corresponds to decelerations, why this clarification may be needed).

Maximum acceleration decreases with speed. When starting from rest, the maximum acceleration for passenger cars can be up to approximately 5 m/s^2. When driving at 40 km/h, the maximum acceleration has decreased to approximately 3 m/s^2. For trucks, the corresponding figures are approximately 1.5 m/s^2 when starting from rest and 0.8 m/s^2 when driving at 40 km/h. Lower maximum acceleration can be expected for weak engines, heavier loads and/or gradients. The acceleration rates chosen by drivers under normal conditions are however much lower than the maximum rates. Drivers usually apply a high level of power – although not maximum acceleration – when starting from rest and then gradually reduce acceleration until the desired speed is reached. Mean accelerations from 0 to 40 km/h can be approximated by the linear relationship a_{avg}=2-0.12v [m/s^2], where v corresponds to vehicle speed in m/s. This yields an mean acceleration of 1.44 m/s^2 in the speed interval of 0–40 km/h. (Long, 2000)

Similarly to acceleration, also deceleration pattern can be approximated by linear relationships. Based on old observations, a linear model has been suggested to passenger cars: d_{avg}=3-0.133v [m/s^2], where v corresponds to vehicle speed in m/s (Long, 2000). The interpretation of this relationship is that drivers gradually apply more pressure to the brake pedal as the speed decreases, which leads to an increase in deceleration until the vehicle has nearly stopped. The brake pedal pressure is then usually released in order to avoid a jerk.

Maximum deceleration for passenger cars can be more than 6 m/s^2 (Malkhamah, 2005) and for trucks about 3 m/s^2 (NCHRP, 2003). American guidelines suggest that deceleration rates up to 3–3.5 m/s^2 are comfortable for passenger cars (ITE, 1999; AASTHO, 2004). In a study by Wang and colleagues, deceleration characteristics of passenger vehicles at stop sign-controlled intersections were investigated for a speed range of 40–90 km/h (Wang, 2005). The mean maximum deceleration was in the range of 2.4–2.7 m/s^2, while the mean deceleration was in the range of 1.2–1.4 m/s^2. No clear relationship between deceleration rates and approach speeds was found. Two types of performance indicators are included in the acceleration and deceleration category. The first type is maximum values, which are analysed in certain situations. They are simply defined as:

$$Maximum\,acceleration = \max(a_s)$$

$$Maximum\,deceleration = \max(d_s)$$

$$Maximum\ jerk = \max\left(\frac{d}{dt}a_s\right),$$

$$Maximum\ jerk = \max\left(\frac{d}{dt}d_s\right),$$

where a_s and d_s denote the time series of acceleration and deceleration in a certain situation or for a certain stretch of road. The second type aims at reflecting the magnitude and the frequency of aggressive accelerations and decelerations. Thus, the term “aggressive” must be defined. Based on the data presented above, the following thresholds are suggested for passenger cars:

$$acceleration\,threshold_{car} = 2\,\mathrm{m/s^2}$$

$$deceleration\,threshold_{car} = 2.5\,\mathrm{m/s^2}$$

Maximum acceleration above threshold is thus defined as the maximum value of the acceleration when it exceeds the threshold value, i.e., the red dots in Figure 1. The *number of accelerations above threshold* corresponds to the number of *Maximum acceleration above threshold* (i.e., the number of red dots in Figure 1). If the threshold is exceeded more than once during a 10 s time interval, this counts as a single occurrence of acceleration above threshold.

Maximum deceleration above threshold and the *number of decelerations above threshold* have the same definition, but with another threshold.
Defining thresholds for heavy vehicles is more complicated. This category includes a wide range of vehicle types which have different characteristics. For example, the weight of heavy vehicles ranges from a few tonnes for light commercial vehicles (LCVs) up to 40 tonnes for large goods vehicles, which will have an influence on what levels of accelerations and decelerations that can be reached. As a starting point, the following thresholds are suggested for heavy vehicles:

$$acceleration\,threshold_{hv} = 1\,\mathrm{m/s^2}$$

$$\textit{deceleration threshold}_{hv} = 1.5\ \text{m/s}^2$$

These thresholds may need to be modified depending on type of vehicle.

Beusen et al and Larsson and Ericsson have used slightly different acceleration and deceleration PIs (Beusen et al., 2009; Larsson and Ericsson, 2009). Instead of calculating the mean and the frequency of heavy accelerations/decelerations, they have assessed the percentage of time driven at accelerations/decelerations above certain thresholds. The threshold for acceleration was 1.5 m/s^2 while the threshold for deceleration was 2.5 m/s^2.

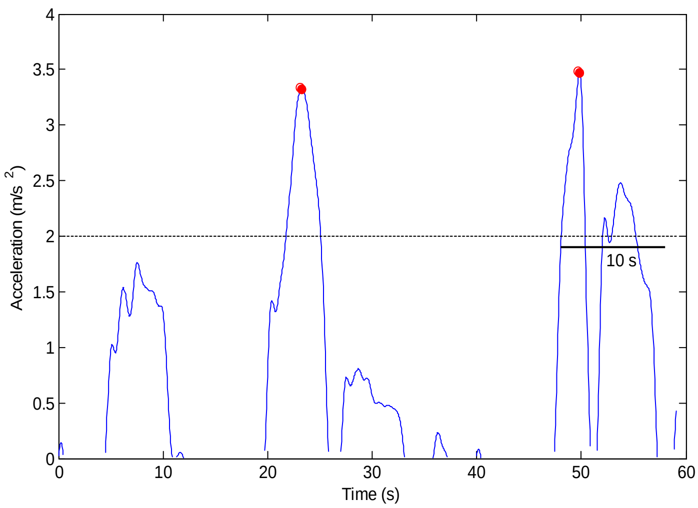


Figure 1: Maximum accelerations (red dots) above threshold (dashed line).

Before calculating any acceleration or deceleration metrics, visual inspection of the data is advisable. Acceleration data is usually noisy and some low pass filtering may be needed.

Hypothesis specific definitions and guidelines	
Hypothesis:	Driving will be more smooth when using an ecoDriver system
Definitions/ guidelines:	*Mean maximum accelerations above threshold* *Mean maximum decelerations above threshold* *Number and frequency of accelerations above threshold* *Number and frequency of decelerations above threshold* These PIs are intended to reflect driving in general, why they should be calculated for the entire data set, according to the definitions above.
Situational variables:	Vehicle type Road type Hilliness

Hypothesis:	Acceleration after standing still will be more aggressive when using an ecoDriver system
Definitions/ guidelines:	*Max acceleration* This PI is defined as the maximum acceleration within 10 s when starting from rest. Only situations where the vehicle is standing/driving within a lane should be included, e.g., at intersections, traffic lights, pedestrian crossings etc. Situations where the vehicle is starting from a parking lot or similar should not be included. Neither should stops due to congestions be included.
Situational variables:	Vehicle type Road type
Hypothesis:	Deceleration when entering safety critical locations/situations will be less aggressive when using an ecoDriver system
Definitions/ guidelines:	*Maximum deceleration* *Maximum jerk* These PIs are defined as the maximum deceleration/jerk within 10 s before entering a safety critical situation/location. What situations/locations to include will depend on the route. Examples are intersections, traffic lights, corners, pedestrian crossings and slow vehicles. It is suggested to analyse all situations together, but it some cases it may be justified to divide them into different SVs.
Situational variables:	Vehicle type (Type of safety critical location/situation)

Sensors and/or Measures needed

Accelerometer

Speedometer

Map

(Front radar, for detection of slow vehicles)

Situational variable considerations and pitfalls in general

- The acceleration/deceleration thresholds may need to be modified depending on type of vehicle.
- Traffic density and car-following state may have an influence on accelerations and decelerations.
- On hilly roads, a steady speed may be unfavourable from an eco-driving perspective. Hilly roads should thus be analysed separately.

4.2.2 AttenD

Description

AttenD (Kircher, 2009) is based on a 3D model dividing the car into different zones such as the windshield, the speedometer, the mirrors, the dashboard, etc., and on the time the driver is looking towards these zones. The algorithm works according to the principle that not only long single glances, but also frequent glances away from what is called the field relevant for driving (FRD), are a sign of driver distraction. A further built-in assumption is that glances to the mirror and the speedometer are necessary for safe driving. Only when they are longer than one second are they treated as distractions. When looking back to the road from having looked at an in-vehicle target the driver needs to adapt physiologically to long-distance focusing. Within AttenD this process is assumed to last 0.1 seconds.

For gaze tracking, the FRD is defined as the intersection between a viewing cone of 90 degrees and the vehicle windows. It is assumed that everything inside the vehicle except for the mirrors and the speedometer is irrelevant for driving. The size of the FRD is relatively generous to allow a proper scanning behaviour of the surrounding traffic situation, for example in junctions and during overtaking manoeuvres. When gaze tracking fails, AttenD switches to head tracking. However, the world model and the zone information are only available for gaze tracking why the FRD has to be redefined. Consequently, the FRD is simplified to a cone of 90 degrees which is cut off at 22.5 degrees downward (where the vehicle interior is assumed to begin).

The general idea behind the AttenD algorithm is that the driver has a time buffer of a maximum level of two seconds, which gets depleted in real time when the driver looks away from the FRD. When the gaze direction is redirected towards the FRD again, the buffer starts filling up after the latency period of 0.1 seconds. When the driver glances at the mirrors or the speedometer, the buffer starts decreasing after a latency period of one second. An example of how the time buffer changes over time is given in Figure 2. This illustrates the development of the attention buffer for three consecutive one-second glances away from the FRD, marked dark grey, with half-second glances back to the FRD in between. In the example a warning would be issued at the time point -5 s, unless inhibited. Note the 0.1 s latency period before increasing the buffer again. A glance to the rear view mirror is exemplified between -1.8 s and 0 s, note the 1 s latency period before the buffer starts to decrease.

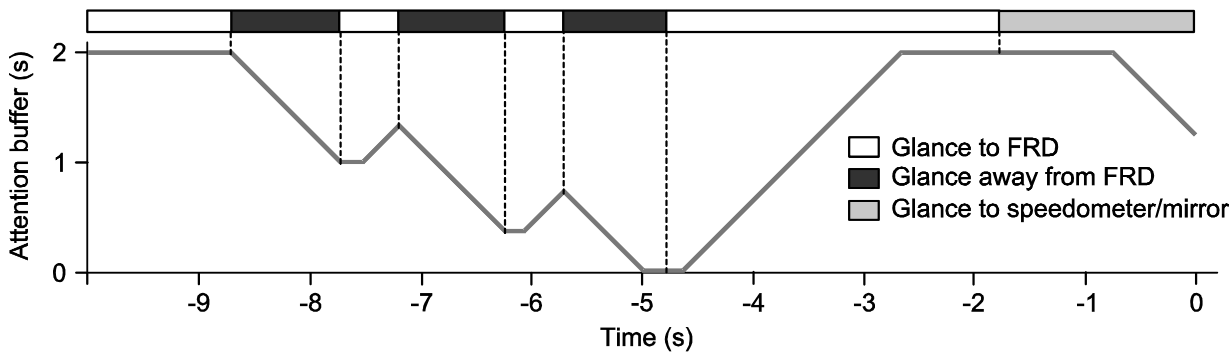


Figure 2: Time trace for three consecutive 1 second glances

When no tracking is available at all, the head direction vector in combination with the buffer value when tracking was lost determines the development of the buffer. If the buffer was smaller than 0.4 s, it will decrement further as long as tracking is unavailable. The reasoning behind this is that a driver who has reached a buffer level of 0.4 s or lower has looked outside of the FRD for a substantial amount of time in the last seconds. It is therefore likely that the loss of tracking is due to glances that are too far out in the periphery to be detected reliably. If the buffer value was 0.4 or larger, the buffer will only decrement further if the last registered head direction vector lay outside of 20 degrees forward, otherwise it will remain at the current level until tracking is possible again. It was reasoned that for a driver who has not yet reached a very low buffer level before tracking was lost the probability is higher than other reasons might have caused the loss of tracking. The driver's face might be covered, or the camera might be obscured for other reasons. Therefore, the buffer is decremented only when the head direction vector is relatively far away from straight forward. A summary of the different thresholds that are used by AttenD is given in Table 6.

Table 6: Summary of the different thresholds and parameters used by AttenD.

Variable	Value
Maximum size of time buffer	2.0 s
Physiological adaptation delay	0.1 s
Mirror and speedometer delay	1.0 s
Increment rate	1 s/s
Decrement rate	1 s/s

Hypothesis specific definitions and guidelines	
Hypotheses:	The driver is more distracted (eyes more “off the road”) with an ecoDriver system that gives in-car feedback. There will be more visual distraction with nomadic devices (smart phones with small screens) than with an embedded system
Definitions/ guidelines:	The hypotheses uses AttenD to get a general value of how visually distracted the driver is. Use the mean AttenD value to get an aggregated value.
Situational variables:	The driver’s scanning behaviour depends on many factors such as road type, rural/urban, curvature, traffic density, weather, intersections, presence of pedestrians, light conditions. However, if Attend is measured over a longer period of time most of these should be averaged out.

Sensors and/or Measures needed

Eye tracker with world model

Vehicle speed

Steering wheel angle

Brake pedal pressure

Situational variable considerations and pitfalls in general

- Eye tracking availability and quality affects the AttenD metric. Factors that affect quality include:
  - Facial features
  - Make up
  - Sudden changes in light conditions
  - Uneven roads

4.2.3 Driver assistance systems

- Percentage of time/distance with system active [%]

Description

This PI is defined as the percentage of time or distance a particular system is active:

$$percentage\ active = \frac{time_{systemActive}}{¿tal\ time} \times 100$$

$$percentage\ active = \frac{distance_{systemActive}}{total\ distance} \times 100$$

Hypothesis specific definitions and guidelines	
Hypothesis:	The use of speed assistance systems will increase when using an ecoDriver system
Definitions/ guidelines:	*Percentage of time/distance with system active* The PIs are calculated according to the definitions above.
Situational variables:	Vehicle type Road type

Sensors and/or Measures needed

System active/inactive

Odometer

Situational variable considerations and pitfalls in general

- Traffic density may have an influence on the use of (speed assistance) systems

4.2.4 Emissions

- Grams of NOx per 100km
- Grams of CO per 100km
- Grams of PM10 per 100km

Description

These PI's cannot be obtained using appropriate sensors as they are too expensive and not enough reliable. Instead, the proposed methodology is based on emission models available at TNO (Versit +).

Versit+ models "regulated emissions" (CO, NOx, PM10, HC, and some other less important ones) as well as CO2, 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.

Versit+ requires first of all the speed and acceleration of equipped and unequipped vehicles, at 1 Hz frequency. This data is used to determine the driving pattern and calculate from that emission estimates, using the patterns from the Versit+ database. For a reliable and accurate calculation, more information than just speed and acceleration is needed. The data requirements for Versit+ are provided in Annex A.

Hypothesis specific definitions and guidelines	
Hypothesis:	Using ecoDriver system will reduce the average GEG emissions
Definitions/ guidelines:	NOX can be derived from instant speed and acceleration signals with the help of Versit+ models.
Situational variables:	Vehicle type

Sensors and/or Measures needed

Instant speed (1Hz)(CAN)

Instant acceleration (1Hz)(CAN)

Slope (map information)

Additional needed parameters for the vehicles can be found in Annex A.

Situational variable considerations and pitfalls in general

- Vehicle parameters are good to know, otherwise average parameters will be used.

4.2.5 Engine brake

- Percentage of engine brake [%]

Description

Percentage of engine brake is defined according to:

$$percentage\, engine\, brake = \frac{time_{engineBrake}}{total\, time} \times 100,$$

where $time_{engineBrake}$ is defined as the total time where all the following criteria are fulfilled:

- Speed > 0
- Vehicle not in neutral
- Accelerator pedal pressure = 0
- Brake pedal pressure = 0

Total time is the total driving time.

A similar PI has been suggested by Beusen et al: *Percentage distance coasting* which is the percentage distance covered during prolonged coasting actions (prolonged coasting is defined as period of at least 3 seconds while fuel consumption = 0, and speed > 0) (Beusen et al., 2009).

Hypothesis specific definitions and guidelines	
Hypothesis:	The usage of the engine brake will be improved when using an ecoDriver system
Definitions/ guidelines:	*Percentage of engine brake* The PI is calculated according to the definition above.
Situational variables:	Vehicle type Gearbox type Road type

Sensors and/or Measures needed

Speedometer

Gear (CAN)

Accelerator pedal position (CAN)

Brake pedal pressure (CAN)

Situational variable considerations and pitfalls in general

- The effect of engine braking varies among vehicle types and gearbox types. It may thus be necessary use both vehicle type and gearbox type as SVs.

4.2.6 Fuel consumption

- Fuel litres per 100km
- Mega joules per 100km
- Grams of CO2 per 100km

Description

The fuel consumption is known to be linearly related to CO2 emissions and energy consumption. Thee three variables are dependent upon each other but converting fuel to energy will allow comparisons between petrol and electrical vehicles.

The primary information on fuel consumption will come from the CAN bus or from estimated models if CAN is not available. On CAN buses, fuel consumption is usually provided as a cumulative value which need to be transformed as an instantaneous signal. The CO2 emissions can be obtained using the following formulas.

- CO2 emissions per km =
  - In the case of petrol engine, consumption within this km (in l/fuel) x 2370
  - In the case of diesel engine, consumption within this km (in l/fuel) x 2650

Conversions formulas from various energy sources can be find at the following location: http://ecotec-systems.com/Resources/FUEL_CONVERSION_WORK_SHEET.pdf

Hypothesis specific definitions and guidelines	
Hypothesis:	The related hypothesis depends on car types (petrol, diesel, HEV, EV) Using ecoDriver will reduce the average fuel consumption Using ecoDriver system will reduce the average energy consumption Using ecoDriver system will reduce the average CO2 emissions
Definitions/ guidelines:	PI's must be computed for a specified trip, or sections of the trip Average of: - fuel litres per 100km - Mega joules per 100km - Grams of CO2 per 100km
Situational variables:	Road type, speed limit, weather, traffic density, system type, hilliness

Sensors and/or Measures needed

For petrol/diesel vehicles:

- Cumulative fuel consumption (CAN)

For electric vehicles:

- Current phase and voltage between phases of the traction motor

- DC filter CVS
- Batteries voltage and temperatures

Situational variable considerations and pitfalls in general

Energy consumption depends on in-cars equipments, and the way they are used. It also depends on the vehicles weight and load. In order to minimize such hard to measure effects, it is recommended to adopt a common approach on how vehicles are used (at least for controlled experiments).

The following recommendations are made:

- Windows closed
- Normalize the loads of experimental vehicles
- Avoid too low temperatures
- Do not use air conditioning

- If such equipments are used, then it should be documented in the data.
- PI's must be computed for a specified trip, or sections of the trip. It is recommended to split each trip into smaller sections (30 seconds for example) according to situational variables of importance that need to be kept constant on this section.

4.2.7 Glance statistics

- Total glance duration
- Glance frequency
- Single glance duration
- Visual time sharing towards a device

Description

Classical glance statistics, for example such as described in ISO 15007-1:2002, have long been used to set up guidelines for appropriate design of in-vehicle devices. Even though many definitions are based on manual coding of video recordings, they can be adopted to automatic eye tracking in a straight forward manner.

A glance is defined as a number of fixations and saccades directed towards a particular gaze target. The *single glance duration* is the time from the moment at which the gaze moves towards the target to the moment it moves away from it, see Figure 3. *Total glance time* is the sum of all glances towards a target during a pre-defined task. Similarly, *glance frequency* is the number of glances to this target during the *total task time*. It should be noted that the glance duration includes the transition time to the target. *Visual time sharing* is the total glance time divided by the total task time.

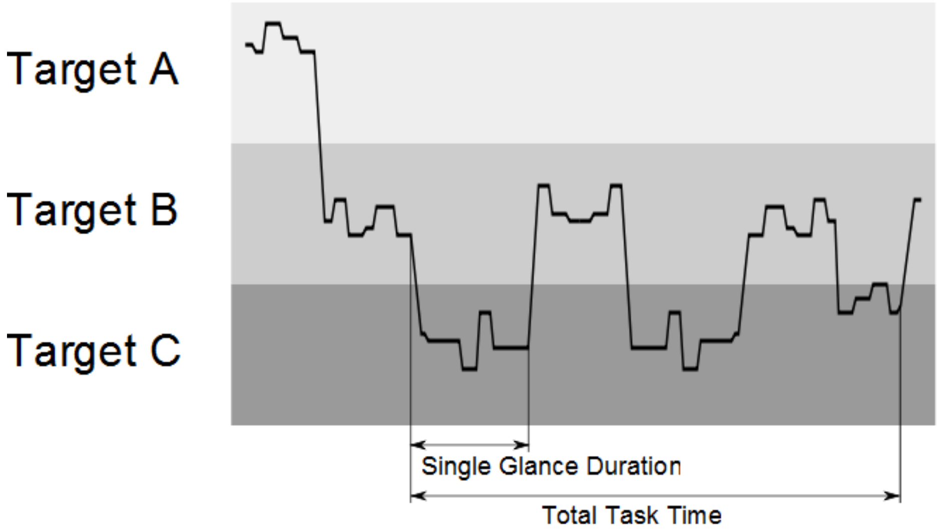


Figure 3: Illustration of single glance duration and total task time to target C.

<table>
<tr><th colspan="2">Hypothesis specific definitions and guidelines</th></tr>
<tr><td>Hypothesis:</td><td>In-car feedback from the ecoDriver system cause inappropriate/dangerous visual behaviour, in terms of glances towards the device</td></tr>
<tr><td>Definitions/ guidelines:</td><td>Mean/max single long glance
Mean/max total glance duration
Mean glance frequency
Mean/max total task time
Mean/max visual time sharing
Rough thresholds, according to the IVIS DEMAnD Modeling Project, on the red level should never be exceeded, and only occasionally at the yellow level (Bischoff 2003):
<table>
<tr><th>Measure</th><th>Yellow</th><th>Red</th></tr>
<tr><td>Single long glance</td><td>1.6 s</td><td>2.0 s</td></tr>
<tr><td>Number of glances</td><td>6 glances</td><td>10 glances</td></tr>
<tr><td>Total task time</td><td>7 s</td><td>15 s</td></tr>
</table></td></tr>
<tr><td>Situational variables:</td><td>Only interesting in the surrounding of an advice from the ecoDriver system.
Compare to guidelines instead of baseline.</td></tr>
<tr><td>Hypothesis:</td><td>The driver will look more at the speedometer/rev counter when using the ecoDriver system</td></tr>
<tr><td>Definitions/ guidelines:</td><td>Same as above, but glances to the instrument cluster instead of the device</td></tr>
<tr><td>Situational variables:</td><td></td></tr>
<tr><td>Hypothesis:</td><td>There will be more visual distraction with nomadic devices (smart phones with small screens) than with an embedded system</td></tr>
<tr><td>Definitions/ guidelines:</td><td>Mean/max single long glance duration
Mean/max total task time</td></tr>
<tr><td>Situational variables:</td><td>Select pairs of data from similar surroundings, preferably the same locations, in the comparison between the system types. If that is not possible, use the situational variables road and weather.</td></tr>
</table>

Sensors and/or Measures needed

Eye tracker

Situational variable considerations and pitfalls in general

- Proper calculation of glance statistics necessitates a segmentation of the eye tracking data partly in different zones, the gaze targets, and partly into fixations and saccades. The zone segmentation is very much dependent on eye tracking quality. Also, fixation segmentation is an unresolved issue. The algorithm choice depends on the quality of the data and the end result depends on the algorithm of choice. A good starting point is to use a velocity based method to find saccades followed by a dispersion based algorithm that add removes saccades based on how likely the fixation is based on its amplitude and duration.

4.2.8 Headway

- Distance headway [m]
- Time headway [s]

Description

Headway describes the time or distance between a lead vehicle and a following vehicle. Distance headway is usually defined as the distance between the front bumper of the lead vehicle and the front bumper of the following vehicle, while time headway is the time it takes from the moment the lead vehicle passes through a specific point until the following vehicle passes through the same point. However, there are several different definitions present in the literature. (Savino, 2009)

Given the experimental setting and the sensors available, a slightly different definition is used here. *Distance headway* is defined as the distance between the front bumper of the following vehicle and the rear bumper of the lead vehicle. *Time headway* is defined as the time from the moment the following vehicle passes the point s_0 until the following vehicle passes the point s_0+s_{DH0}, where s_{DH0} denotes distance headway at the point s_0. The variable s can be obtained either from the odometer (if it has high enough resolution) or indirectly from vehicle speed.

The following criteria must be fulfilled in order to calculate headway measures:

- The vehicles must travel in the same lane
- The road must be relatively straight

Usually, the range of the radar sets a natural limit for the range of headways that can be calculated. Otherwise, it is suggested that only headways of approximately < 150 m should be considered for analysis.

Headway measures that reflect the distance between the rear of the lead vehicle and the front of the following vehicle are sometimes called gap, gap distance or time gap instead of headway.

Hypothesis specific definitions and guidelines	
Hypothesis:	There will be shorter distances to following vehicles in/during safety critical locations/situations when using an ecoDriver system
Definitions/ guidelines:	*Distance headway* The distance between the front of the following vehicle and the rear of the lead vehicle (i.e., the experimental vehicle). *Time headway* Since the experimental vehicle is the lead vehicle in this case, time headway at position s_0 can be calculated as the time difference between the moment the experimental vehicle passes through s_0 and the moment where s_t-dh_t equals s_0, where s_t and dh_t are the position and distance headway at time t, respectively. Both these PIs are defined as the mean value over a time interval that starts 10 s before the experimental vehicle enters a safety critical situation/location. What situations/locations to include will depend on the route. Examples are intersections, traffic lights, corners, pedestrian crossings and slow vehicles. It is suggested to analyse all situations together, but it some cases it may be justified to divide them into different SVs.
Situational variables:	Vehicle type Road type

Sensors and/or Measures needed

Rear radar

Speedometer

Odometer

Map

(Front radar, for detection of slow vehicles)

Situational variable considerations and pitfalls in general

- Traffic density is expected to have an influence on headway measures.

4.2.9 Overtaking

- Number of overtaking per 100 km [-]

Description

This PI is defined as the number of overtaking per 100 km done by the driver of the experimental car. Only two lane rural roads with oncoming traffic should be included.

The most reliable way of determining the number of overtaking is to analyse video films of the front view. This can however be very time consuming and it might therefore not be possible to conduct such an analysis. An alternative is to implement an overtaking detection algorithm, based on lane tracker, radar and map data. A further alternative is to use this PI only for controlled trials and let the observer log overtaking behaviour.

Hypothesis specific definitions and guidelines	
Hypothesis:	There will be fewer overtaking when using an ecoDriver system
Definitions/ guidelines:	*Number of overtaking per 100 km* The PI is calculated according to the definition above.
Situational	Vehicle type

variables:	(Road type)

Sensors and/or Measures needed

Front video and/or observer

Lane tracker

Front radar

Map

Situational variable considerations and pitfalls in general

- Traffic density may have an influence on the number of overtaking.

4.2.10 Range over range rate

- Range over range rate

Description

Typical attributes of eco driving are correct choice of speed and gear, minimized acceleration and deceleration, coasting, gliding and anticipation. To facilitate smooth driving, it is likely that the driver waits just a little longer before applying the brakes if he/she feels that it might not be necessary. This may mean that the driver is voluntarily violating the "comfort zone" surrounding his/her vehicle in order to avoid unnecessary decelerations.

The safety zone, i.e., the boundary representing the limits of possible action, is an objective measure of for example the minimum time to collision that is necessary to avoid a crash by braking. Similarly, the comfort zone provides a boundary that minimizes discomfort. The distance between the subjective comfort zone and the objective safety zone is the safety margin selected by the driver (Summala 2007).

In order to answer this hypothesis, it is necessary to define safety zone and comfort zone. This is not straight forward since the safety zone depends on the capabilities of the driver and on several situational variables such as friction, road curvature etc. Since eco driving is mostly about longitudinal control, we restrict the definitions to longitudinal concepts. The safety zone is defined according to Najm and Smith (2004), with the safety zone boundary according to the low risk threshold (Figure 4).

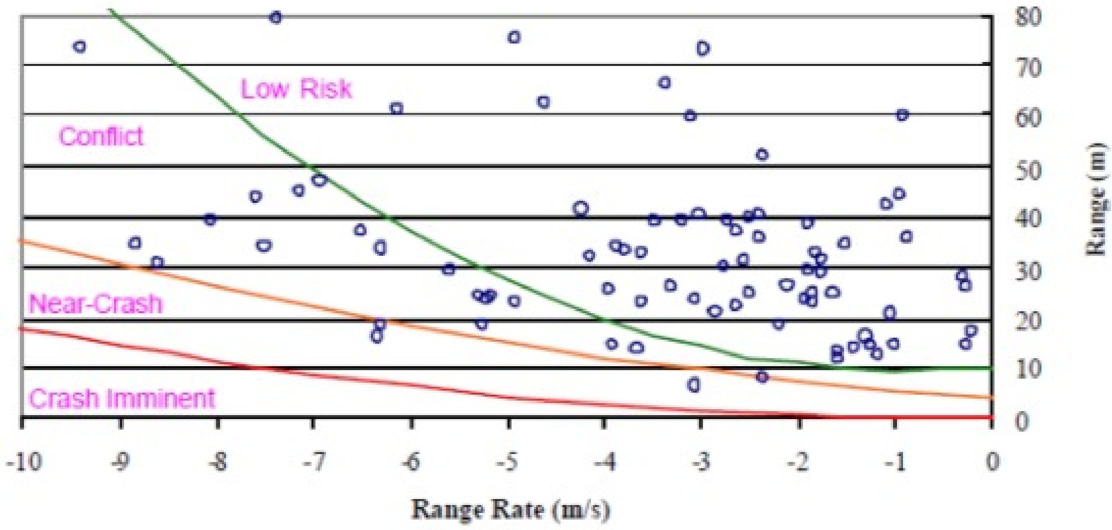


Figure 4: Different thresholds to indicate risk as a function of range over range rate (Najm and Smith 2004).

Hypothesis specific definitions and guidelines	
Hypothesis:	There will be fewer occurrences where the vehicle in front is in the driver's safety zone when using an ecoDriver system
Definitions/ guidelines:	Number of range over range rate violations per 10 km, where a violation is characterised as: $R < 1.04\left(\frac{dR}{dt}\right)^2 + 1.65\frac{dR}{dt} + 10$ R is the headway between the lead vehicle and the own vehicle.
Situational variables:	Road friction Speed limit Lead vehicle present No congestion

Sensors and/or Measures needed

Radar or camera (lead vehicle distance and velocity)

Situational variable considerations and pitfalls in general

- Road friction: Lower friction can lead to drivers keeping larger distances in general.
- Speed limit: Different speed limits lead to different distances, therefore it is necessary to compare data from the same speed limit sections.
- Lead vehicle present: When no lead vehicle is present, the frontal safety zone cannot be violated by another vehicle.
- No congestion: In congestions at low speeds the measure is not valid, therefore such occurrences have to be excluded.

4.2.11 Speed

- Mean speed [km/h]
- Instantaneous speed [km/h]
- Percentage speeding [%]

- Positive kinetic energy [m/s²]
- Spectral arc length of speed [-]
- Standard deviation of speed [km/h]

Description

Mean speed and *standard deviation of speed* is calculated either for a whole trip or dataset, or for a certain stretch of road. *Instantaneous speed* is the speed at a certain point along the road. *Percentage speeding* is defined according to:

$$percentage\ speeding = \frac{distance_{speeding}}{total\ distance} \times 100,$$

where *distance speeding* is the distance where speed is ≥ 0 km/h above the posted speed limit (Beusen et al., 2009). *Total distance* corresponds to the total stretch of road that is analysed. *Speeding speed* is the mean speed while speeding, i.e.,

$$speeding\ speed = mean(v_{speeding})$$

where $v_{speeding}$ > posted speed limit.

The PI *positive kinetic energy* (PKE) aims to quantify how well the driver anticipates the traffic flow. PKE is calculated as (Andrieu and Saint Pierre, 2012):

$$PKE = \frac{\sum(v_f^2 - v_i^2)}{x} \text{ when } \frac{dv}{dt} > 0$$

where x is the total distance when dv/dt > 0, where v_f and v_i are the final and the initial speed at each time interval for which dv/dt > 0, respectively. This indicator represents the ability to keep the vehicle's kinetic energy as low as possible. A nervous driving will be associated with a high PKE whereas smooth driving will be associated with a PKE close to zero.

Spectral arc length of speed (SAL) is a measure of smoothness. It is defined as negative arc length of the amplitude- and frequency normalized Fourier magnitude spectrum of the speed profile (Balasubramanian 2011):

$$SAL = -\int_0^{\omega_c} \sqrt{\left(\frac{1}{\omega_c}\right)^2 + \left(\frac{d\hat{V}(\omega)}{d\omega}\right)^2} d\omega, \hat{V}(\omega) = \frac{V(\omega)}{V(0)}$$

Here V(ω) is the Fourier magnitude spectrum of v(t) where tϵ[0,T], and $[0,\omega_c]$ is the frequency band of interest. This performance indicator is dimensionless, monotonic, robust and sensitive to changes in movement characteristics.

Depending on the type of sensor, some filtering of the speed data may be needed before the PIs are calculated.

Hypothesis specific definitions and guidelines	
Hypothesis:	Mean speed will be equal or lower when using an ecoDriver system
Definitions/ guidelines:	*Mean speed* This PI is intended to reflect speed in general and it should therefore be calculated for all data. However, low speed roads (urban areas) should be separated from high speed roads (rural roads, motorway) in the analysis.
Situational variables:	Vehicle type Road type
Hypothesis:	Speed will be higher when driving through/past locations were a low speed is recommended when using an ecoDriver system
Definitions/ guidelines:	The PIs should be applied to five different locations: - Intersections without traffic lights - Zebra crossings - Speed reducing measures - Corners/sharp curves - Villages The locations should be analysed separately. *Mean speed* For intersections, zebra crossings, speed reducing measures and corners/curves: mean speed should be calculated over an interval starting 100 m before the location and ending 50 m after the location. For villages, it is not possible to set up a definition. The stretch of road to analyse must be defined for each village of interest. It is recommended to include only small villages where the driver is expected to reduce the speed over a rather short stretch of road. *Instantaneous speed* For intersections, zebra crossings, speed reducing measures and corners/curves: instantaneous speed should be calculated right before the location. For villages, the point where instantaneous speed should be analysed must be defined for each village.
Situational variables:	Vehicle type Road type Traffic density
Hypothesis:	There will be more occasions of speeding when driving downhill when using an ecoDriver system
Definitions/ guidelines:	*Percentage speeding* *Speeding speed* The PIs are calculated for (steep) slopes. The beginning and the end of the slope must be defined for each slope.
Situational variables:	Vehicle type Road type
Hypothesis:	Driving will be more smooth when using an ecoDriver system
Definitions/ guidelines:	*Positive kinetic energy* *Spectral arc length of speed* *Standard deviation of speed* These PIs are intended to reflect driving in general and should thus be calculated for all data.
Situational variables:	Vehicle type Road type Hilliness

Sensors and/or Measures needed

Speedometer

Map

Situational variable considerations and pitfalls in general

- Traffic density may have an influence of speed PIs
- Speed PIs may be influenced by the use of speed assistance systems
- Spectral arc length is affected by the window size why a fixed size should be used throughout the analysis for this PI.
- On hilly roads, a steady speed may be unfavourable from an eco-driving perspective. Hilly roads should thus be analysed separately.

4.2.12 Traffic light violations

- Number of red light violations per 100 km [-]
- Number of amber light violations per 100 km [-]

Description

A traffic light violation occurs if the light is amber or red the moment the driver enters the intersection, i.e., crosses the line where he is supposed to stop in case of amber/red light.

Red/amber light violations can, in theory, be identified either from observations (accompanied driving sessions) or from video analysis. It is however suggested that traffic light violations only should be analysed for driving sessions where no observer is present. Thus, traffic light violations must be identified from video analysis. This can be somewhat complicated for several reasons. First, such an analysis may be very time consuming. Furthermore, poor video quality can make it difficult to identify the colour of the traffic light, and in some cases the traffic light may not even be visible in the video films at all, either because of the angle of view of the video camera or because of the position of the traffic light. Therefore, the definition above may not be possible to apply in practice, why some modifications may be needed.

Hypothesis specific definitions and guidelines	
Hypothesis:	There will be more red or amber light violations when using an ecoDriver system
Definitions/ guidelines:	*Number of red/amber per 100 km* The PIs are calculated according to the definition above.
Situational variables:	Vehicle type Road type

Sensors and/or Measures needed

Front video

Situational variable considerations and pitfalls in general

- Red/amber light violations are expected to occur relatively rarely. Much data are thus needed in order to get reliable results.

4.2.13 **Visual Demand Metric**

- Visual demand metric

Description

The SafeTE visual demand metric (Engström and Mårdh, 2007) is based on a summation of individual off-road glance durations, where long glances are penalised by means of an exponential function. This sum is referred to as the Weighted Summed Glance Durations (WSGD). In order to account for display eccentricity, the WSGD is multiplied by a factor that penalises eccentric display positions as a function of the radial angle of the display from the normal line of sight. The visual demand imposed when performing an IVIS task is thus defined as:

$$Demand = \sum_{i=1}^{N} g_i^k E(\alpha)$$

where N is the total number of off-road glances during the task, g_i is the duration of off-road glance i (in seconds), k is a constant, E is the so called eccentricity penalty function and α is the radial gaze angle between the forward roadway and the display. The weighting of the single glance duration is done by means of the exponent k according to Wierwille and Tijerina (1993). Its value determines the degree to which long glances are penalised and is here set to k=1.5. The eccentricity penalty function E is estimated based on the observation that driving performance degradation increases with the eccentricity of the in-vehicle target (e.g., the display):

$$E(\alpha) = 6.5758 - 1/(0.001\,\alpha + 0.152)$$

In the final step, the visual demand for the system is transformed into a 5-point rating according to:

Demand < 8	5
8 < Demand ≤ 16	4
16 < Demand ≤ 24	3
24 < Demand ≤ 32	2
Demand ≥ 32	1

Hypothesis specific definitions and guidelines	
Hypothesis:	In-car feedback from the ecoDriver system cause inappropriate/dangerous visual behaviour, in terms of glances towards the device
Definitions/ guidelines:	Average visual demand rating (towards the device) for each occurrence of eco-driving advice. Max visual demand rating
Situational variables:	
Hypothesis:	There will be more visual distraction with nomadic devices (smart phones with small screens) than with an embedded system
Definitions/ guidelines:	Average visual demand rating (towards the device) for each occurrence of eco-driving advice. Max visual demand rating
Situational variables:	

Sensors and/or Measures needed

Eye tracker

Situational variable considerations and pitfalls in general

4.2.14 Percentage Road Centre

Description

Percentage Road Centre (PRC) is a performance indicator that has been used to determine the level of attention. Instead of measuring the glances off road, this measure focuses on measuring how much time is spent monitoring the road centre area while performing a visual task. The rationale behind this measure incorporates the finding that drivers time share not only between the road centre and in-vehicle tasks, but also time share between road centre and other driving related objects such as signs, bicyclists, mirrors, scenery and so on. PRC thus measure how much action guidance information drivers are receiving and this may closely relate to driving performance measures and peripheral event detection probability. PRC has been reported to be sensitive to visual task difficulty and also, albeit to a lesser extent, to auditory task difficulty (Victor, Harbluk & Engström, 2005).

Victor et al. (2005) computed PRC by binning the gaze data which were determined to be fixations into 128 by 128 bins for a 120 by 120 degree portion of the data in the forward view in order to determine the mode, or most frequent gaze angle. The road centre area was then defined as a circle with eight degree radius surrounding the road centre point. PRC is usually calculated in a sliding window of 60 seconds duration, but there is also a PI called PRC_{task} which measures PRC during the duration of some secondary task. Note that if the task duration is too short there will not be enough data to construct the histogram (this can be avoided by subtracting the median value from the vertical and horizontal gaze directions, respectively, instead of computing the 2D histogram).

For normal driving approximately 80% of time is spent looking at road scene ahead, for a visual task reduced % PRC , for cognitively distracting tasks an increase might occur.

Hypothesis specific definitions and guidelines	
Hypothesis:	The driver is more distracted (eyes more “off the road”) with an ecoDriver system that gives in-car feedback.
Definitions/ guidelines:	Percentage road centre is already an aggregated measure. The idea is to get a general picture of the visual behaviour (including more glances to the speedometer, to the ecoDriver device, to the rev counter, and to surrounding traffic) so PRC calculations should not be isolated surrounding certain situations.
Situational variables:	Only fairly straight road segments Only when eye tracking quality is high

Sensors and/or Measures needed

Eye tracking

Situational variable considerations and pitfalls in general

- Gaze concentration to the road centre area has been found to increase with increasing traffic complexity, leading to higher PRC values.

- When driving on roads with many lanes, keeping track of the traffic in all lanes reduces PRC.
- PRC changes with eye tracking quality.
- If head tracking is used instead of gaze tracking, higher PRC values should be expected.
- When driving in curves, the gaze will reside outside the road centre circle even though the driver is looking at the road.
- The ecoDriver system will often give advice in "sticky" situations where the driver is looking away from the road centre anyway. The impact of this PI may therefore be minimal.

4.2.15 Rotational (engine) speed

- Average rpm when shifting gear up [rpm]
- Weighted average engine rpm [rpm]

Description

Average rpm when shifting gear up is defined as the average of the rotational speed the moment right before the clutch is pressed and the gear is shifted up (Beusen et al., 2009).

Weighted average engine rpm is defined as the average rpm by gear when driving, weighted by the time with gear engaged:

$$weighted\ average\ engine\ rpm = \sum_{i \in G} p_i \frac{rpm_i}{5000}$$

where p_i is the percentage of time in gear i, rpm_i is the average engine speed in gear i, and G = {neutral, gear 1,…,gear n}. For gears 1–n, only time periods where the accelerator pedal is pressed should be included. This condition ensures to ignore the time in engine brake (which is investigated by another hypothesis/PI). The division by 5000 is just a normalization factor that can be adapted.

Hypothesis specific definitions and guidelines	
Hypothesis:	The average rpm when shifting up will be reduced when using an ecoDriver system
Definitions/ guidelines:	*Average rpm when shifting gear up* The PI is calculated according to the definition above.
Situational variables:	Vehicle type Road type
Hypothesis:	The weighted average engine rpm will be decreased when using an ecoDriver system
Definitions/ guidelines:	*Weighted average engine rpm* The PI is calculated according to the definition above.
Situational variables:	Vehicle type Road type

Sensors and/or Measures needed

RPM gauge

Instant speed

Gear (derived from instant speed and rpm)

Accelerator pedal

Clutch pedal

Situational variable considerations and pitfalls in general

4.2.16 **Workload**

- NASA TLX

Description

The NASA Task Load Index (NASA-TLX) is a widely used tool for assessment of subjective workload (NASA, 2012a). The rating procedure includes six subscales: mental demand, physical demand, temporal demand, performance, effort and frustration. The overall workload score is derived as the weighted mean of the six subscale ratings. The weights are specific for each subject and they aim to account for differences in workload definition between subjects and for differences in sources of workload between tasks.

The NASA-TLX scale is suggested to be used during the controlled driving sessions. It can be used in two ways: either as a general rating of the workload in relation to the ecoDriver system for the whole driving session, or as a rating in a specific situation when the driver gets feedback from the system. If possible, it is recommended to apply the scale both for the whole session and for specific situations. What specific situations to include will depend on the route and on the type of feedback.

Ratings can only be obtained in observed driving sessions. Shortly after a specific situation (or, for the general rating, in the end of the driving session), the observer will ask the driver to rate her/his workload on the six subscales. This implies that the driver must be familiar with the scale, why some training is needed before the driving session starts.

The weights should be obtained when the driver has had some time to get used to the ecoDriver systems, e.g., after 2–3 driving sessions or later. This procedure is preferably done after one of the driving sessions (not while driving).

A full description of the scale, how to use it and how to derive the overall workload score can be found in the NASA-TLX manual (NASA, 2012b). It is recommended to read this manual before using the scale.

Hypothesis specific definitions and guidelines	
Hypothesis:	The workload of the driver will increase when (s)he has an ecoDriver system that gives in-car feedback.
Definitions/ guidelines:	*NASA-TLX* General rating for the whole driving session: This should be done in the end of the driving session, or immediately after the driving session. Rating of specific situations: This should be done immediately after the situation. Typical situations are those where an "eco-driving behaviour" can be expected or where the system is expected to give feedback (e.g., in intersections). It is suggested to let the driver comment on and explain her/his ratings in order to be able to identify factors (related to the ecoDriver system) that are unfavourable from a workload perspective. Since the rating procedure may be somewhat disturbing to the drivers, it may be a good idea to limit the ratings to a few driving sessions, e.g., one baseline session, one treatment session in the beginning and one treatment session in the end.
Situational variables:	(Type of situation)

Sensors and/or Measures needed

(Observer)

Situational variable considerations and pitfalls in general

- Traffic density may have an influence on workload.

4.3 Situational variables

A situational variable is an aspect of the surroundings made up of distinguishable levels. As such, situational variables describe the surroundings in which the drivers find themselves. Each situational variable has several levels, of which at least one is valid at each point in time. Wherever one is driving, there is always at least one road type, be it rural, urban, motorway, or even terrain driving. Similarly, there is always some kind of weather, and there is always some type of road friction.

In ecoDriver there are two types of situational variables: those that needs to be controlled for (e.g., speed limit), and those that are interesting as experimental factors in themselves such as winter conditions and hilly landscapes. However, in order to keep the analysis manageable and to avoid ending up with "too many cells in the matrix", the aim is to use as few situational variables as possible. These variables should be known to have bearing on fuel consumption.

A great number of situational variables are not expected to have a direct impact on fuel consumption, such as daylight versus darkness. These variables were not included and are not described here. For these reasons, the number of situational variables was limited to road type, hilliness, temperature, road condition, and traffic density. It will be made sure that they can be logged fully at the controlled test sites. Traffic density, road condition and temperature, however, will not necessarily be recordable for all naturalistic fleets, as the necessary sensors may not be present in all fleets.

Depending on the test site, there will be sensors installed in the vehicles that are able to log information for further situational variables, like precipitation, the vehicle weight or the presence of passengers. Observers in the controlled drives will be able to log features that may influence driving behaviour, such as the presence of pedestrians or of road constructions etc. Where possible and meaningful, these variables will be recorded and considered in the analyses.

4.3.1 Road type

Description: Different road types result in different average speeds and different profiles of acceleration and deceleration, for example due to road geometries, road roughness and speed limits. In ecoDriver, the following road types will be used:

• Highway	at least 2 lanes per direction limited access physical barrier between directions
• Rural road	outside built-up areas access not limited
• Urban road	inside built-up areas maximum speed limit 70 km/h (dependent on country) access not limited
• 2+1 road (Sweden)	three lanes middle lane changes direction every few km physical barrier between directions outside built-up areas

In some cases, it may be necessary to differentiate not only between road types but also between speed limits.

Sensors/information needed: Position linked to map data.

4.3.2 Hilliness

Description: The gradient of the road has an influence on fuel consumption. Inclines increase consumption, declines allow fuel savings. Handling accelerations sensibly in relation to crests and the present speed limit can lead to substantial fuel savings.

Sensors/information needed: The gps position of the vehicle will enable the extraction of the local gradient from the map integrated into the ecoDriver system.

Pitfalls: As long as the information in the maps is correct, logging should be straightforward. Exactly how the variable will be used in the analyses will be determined both within WP41 in combination with the WPs planning analysis, as well as with SP5, where gradient will be used in modelling.

4.3.3 Temperature

Description: Temperature has an influence on fuel consumption in a number of ways. With dropping temperatures, fuel consumption increases due to more idling, lower tire pressure, increased rolling resistance, deteriorating road conditions (slush, snow and ice), lower average engine temperature, higher average lubricant viscosity, higher electrical loads (frequent use of lights, defrosters and heaters), and more aerodynamic drag.

Sensors/information needed: Temperature sensor in the vehicle or position and time to acquire temperature from a weather database.

- In the controlled studies, it is recommended to manually store weather information for each trip.
- For connected devices, such as the embedded system, it is recommended that the current weather is automatically downloaded from a suitable weather forecast site and stored along with the rest of the data.

4.3.4 Road condition (wet, dry, ice)

Description: Different road conditions have a large impact on driving speed, with slower speeds for slippery surfaces. This will have an influence on fuel consumption and safety.

Sensors/information needed: Weather database, rain sensor, temperature

Pitfalls: It is not entirely clear how road conditions affect fuel consumption. For example, some argue that rain may increase fuel consumption due to increased rolling resistance while increasing the fuel efficiency in diesel engines since the water vapour mixed with diesel fuel improves the engine performance.

4.3.5 Traffic density

Description:

More dense traffic has two principal influences on drivers; speeds decrease and the frequency and magnitude of vehicle decelerations/accelerations increase. This will have an influence on fuel consumption but also on safety related hypotheses. The level of service on a particular road is often measured as a 2D-function of speed and traffic flow, divided into free-flow, heavy, quasi-saturated and stop and go. From an eco-driving perspective, it is however better to define traffic density on a local scale in the surrounding of the vehicle.

Sensors/information needed: Multi-target radar, road type.

Pitfalls: It is not clear how traffic density should be measured from an eco-driving perspective. Classic definitions of traffic density, such as flow divided by unit of space, may not reflect the driver in question on a local scale. Vehicle based estimates of local traffic conditions require multi-target radars which may not be available in the ecoDriver fleets.

4.4 Explorative analysis

In addition to the conventional hypothesis testing, an explorative or descriptive approach is suggested in order to get a broad overview of the effects of the ecoDriver systems on emissions and driver behaviour. An exploratory review of the data is often crucial to gain an understanding of the characteristics of individual variables, the quality of the data, patterns and relationships between variables and combinations of variables, and subsets of observations within the database. Especially visual approaches to exploratory data mining will be used to gain this understanding; scatter plots, parallel coordinate plots, correlation matrices, probability density plots, and time series analyses are a few key techniques.

Such an analysis may provide a better understanding of how eco-driving influences driving patterns and it could potentially give indications of effects that are not covered by the hypotheses. Examples of interesting exploratory analyses include:

- Exploratory data analysis and time series analysis is of particular interest in the vicinity of predefined targets such as intersections, speed cameras, hills, curves, corners and speed reducing measures. Comparisons between different ecoDriver system types are also of interest.
    - Mean ± std velocity profiles plotted as a function of time in the surrounding of interesting locations and events could show dynamical changes in speed.
    - Range over range rate scatter plots in the above mentioned situations could reveal differences for example between the severity zones.
- Probability density functions of i.e., speed, acceleration, and accelerator and brake pedal pressure.
- Parallel coordinate plots of fuel consumption, speed, vehicle type and landscape features etc.
- Driver response and actions in relation to the advice given by the ecoDriver system
- A key finding in eco driving is that the driver anticipates the dynamics of surrounding traffic in a better way. This observation should be reflected in the scan path of the driver. Analysing the scan path in a systematic manner will, however, require scrutinizing the gaze patterns rather than a scalar PI. Sequence similarity measures may be of interest in such investigations, but it is important to extend current distance measures with a temporal dimension.

From a road safety perspective, it may be difficult to link performance indicators to actual crash risk. It may therefore be interesting to investigate a number of more pragmatic measures to enhance the safety related validity. Instead of mainly using scalar performance indicators that describe the control level of driving behaviour, it is suggested to develop indicators that describe the tactical level. These are expected to be easier to understand and interpret. It is also assumed that the tactical level is affected by external factors sooner than the control level is. These performance indicators should have an inherent link to violations or other behaviour that already has been linked to an increased risk in traffic. In order to incorporate the qualitative/quantitative aspect of behavioural differences it may be meaningful not only to evaluate the difference in mean values between groups, but to focus on the percentage of drivers who are able to perform a task within given boundaries, for example, take in information from the ecoDriver system while remaining within one's lane and within a certain speed interval. Another example is the number of red or amber light violations that may occur if the driver becomes reluctant to brake in order to save fuel.

4.5 Data Acquisition Demands

As analyses will be made in a similar fashion for all test sites, it is necessary to make the data logging procedures for comparable data acquisition systems as comparable as possible. The technical details are to be specified within SP3. Here the basic sensor demands are given (Table 7). As the data acquisition systems and other sensors will be selected centrally, and mounting instructions will be developed centrally, it will be ascertained that the collected data are comparable across test sites.

Table 7: Demands on sensors for performance indicator calculations

Sensor	Sample rate (Hz)	Accuracy	Quantization level	Other requirements
Accelerator pedal pressure (CAN)	10		1 %	
Accelerometer	10		0.01 m/s^2	
Air condition on/off	1			Should be always off for simplification purposes
Battery status (only for FEVs)	10			For further information, see section 4.2.6.
Brake pedal pressure (CAN)	10		1 %	
Clutch pedal pressure (CAN)	10		1 %	
Eye tracker (gaze direction)	50	5°		No baseline drift
Eye tracker (head direction)	50	5°		No baseline drift
Front radar	10		0.1 m	
Front video	ca 10–20			Wide-angle view
Fuel consumption (CAN)	10			
Gear (CAN)	10	-	-	If available, otherwise reconstructed from instant speed and rpm
GPS	10		0.001 min	10 m range precision
Lane tracker	10		0.01 m	
Map				Should include information on: road type, posted speed limit, intersections, traffic lights, pedestrian crossings, gradient, speed reducing measures, curvature, etc.
Odometer	10		1 m	
Rear radar	10		0.1 m	
RPM gauge	10	10 rpm		
Speed (CAN)	10	1 km/h		
Speed (GPS)	1	1 km/h		GPS speed is obtained using the Doppler effect and is very precise and stable. This signal is independent from GPS position.
Speed assistance system active/inactive (CAN)	10	-	-	It is recommended not to use such systems for controlled experiment. Obtaining this CAN signal from the OEM is very hard.
Load	-			Cannot be measured automatically (use questionnaires instead?)

Table 8: Data sources for situational variables

Data source	Sample rate	Accuracy	Quantization level	Other requirements
Weather	1/h		5 km^2	
Traffic density	1/minute		Low, medium, high	
Map				
Thermometer, outside			1°	
Thermometer, in car			1°	
Road condition	1/minute			Dry, wet, snow, ice

5. Procedures

The field trials aim to investigate the following key performance of the ecoDriver system:

- User acceptance of the ecoDriver system and compliance of the advice across the three phases: pre-trip, real-time, and post-trip.
- Effect of the ecoDriver system on energy efficiency (i.e., the system aims to reduce energy consumption by 20%) as well as associated emission reduction
- Potential impact on safety due to distraction related issues

Many elements of the experimental design relate to the functionalities of the ecoDriver system; for example:

- Content of eco-driving advice
- Timing of information provision
- Configuration of HMI

These aspects are mainly dealt with in SP1. At the time of producing this deliverable, the final solutions for the field trials have not yet been identified. As a result, some aspects of the experimental design and trial procedures could not have been finalised. However, as a first step, decisions have been made regarding what type of study that was to be carried out in the respective test fleets, as depicted in Table 9.

Table 9: Final decision on type of study per test fleet

Test fleet #	Vehicles	Type of study
1 (FR)	10 passenger cars	Naturalistic
2 (FR)	2 passenger cars	Controlled
3 (DE)	1 passenger car	Controlled
4 (DE)	1 passenger car	Controlled
5 (DE)	1 truck	Controlled
6 (DE)	10 LCVs or trucks	Naturalistic
7 (IT)	4 passenger cars	Controlled
8 (NL)	10 LCVs or trucks	Naturalistic
9 (ES)	10 passenger cars	Naturalistic
10 (ES)	2 passenger cars	Controlled
11 (SE)	1 passenger car	Controlled
12 (UK)	10 buses	Naturalistic

For the controlled studies, it was suggested to keep some similarity between the different experiments for several reasons:

- It will simplify analyses if similar/the same scripts can be used for data analyses.
- It will allow some comparison across countries, even though confounding effects surely can be present anyway.
- It will potentially strengthen the conclusions if a certain effect is demonstrated at several test sites.
- It will give the project an extra dimension if drivers from different test sites can relate to others' experiences.
- It will make the experimental design easier and more time efficient.
- It will help sorting the hypotheses into "can do" and "cannot do", if a preliminary experimental design is suggested.

A common design setup was thus proposed, which aimed at providing a "skeleton" or a basis describing the minimum requirements that have to be fulfilled by all controlled test fleets. Extensions to the skeleton will be possible in order to adapt it to local circumstances or to test hypotheses that are specific for certain test fleets.

On the other hand, naturalistic experiments will contribute to fundamental understanding of driver interaction with the ecoDriver system across a wide range of circumstances. The experimental design and associated trial procedures are more bespoke to resources available to each VMC.

5.1 Ethical aspects

Each VMC is responsible to ensure that all ethical requirements are fulfilled for running the study. In the case that ethical approval has to be obtained from an official entity, it lies within the responsibility of each VMC to do this well in time to run the trials.

5.2 Experimental design

Considerations were given among the following three experimental designs:

- A-B: comparison between driving without ecoDriver and with ecoDriver
- A-B-A: as the A-B design, with the added benefit of examining carry-over effect
- A-B-C: this focuses on comparative benefits of the ecoDriver system over generic eco-driving devices

In addition to the debates over the three different designs, concerns also lie in the uncertainty of differences between the full ecoDriver system and the portable version of the ecoDriver system (i.e., the core ecoDriver algorithm implemented on a nomadic device), which is dependent on work in SP1 and SP2. Further concerns are with the compromise between system exposure and sample size. It is an extremely challenging task of standardising experimental design among all VMCs. It has therefore been agreed at this stage that all three experimental designs will be used, but spread across VMCs. The aim of this plan is to generate a wide variety of data for validating hypotheses.

5.3 Driver selection criteria

The selection criteria pertain to those fleets that can have an influence on the choice of the drivers. TomTom and Leeds will almost certainly do not have a choice on the drivers that will participate since they select them from fleet owners. Daimler may be able to exert more influence but given the fact that it is an internal delivery truck of Daimler most likely they will have a limited pool of drivers. IKA, CTAG, BMW, VTI, and IFSTTAR do have influence on who participates.

Consequences of choices

Preferably any experiment contains a representative sample. The question is what is meant by representative. It can be representative for an entire population which means that there has to be an equal distribution in the sample with respect to male/female, age classes, driving experience, etc. It can also be representative for the population that uses eco driving applications. However the choice of the participants also depends on what the data are used for. In ecoDriver the data are also used for scaling-up. This suggests that the sample needs to be representative for the entire population. At the same time the objective of ecoDriver is to personalize the feedback and HMI to increase compliance and usage of otherwise non-users (e.g., sporty drivers). This would mean that drivers with specific characteristics need to be included. Furthermore, not much can be said on the effect size of the system (how much the energy usage decrease with the use of the ecoDriver system). This would suggest choosing a group of drivers as homogenous as possible to minimize the variance between drivers and thereby increasing the chance of finding an effect. Given the limited possibilities within the real world trials in SP3 (limited in duration, in vehicles and resources) clearly choices have to be made.

Minimum requirements of drivers

The minimum requirements of drivers for fleets in which we have a choice are:

- Minimally five years in possession of a full driver license
- Drive minimally 10000 km a year
- Age 30 – 55 (unless age group is a specific focus of the test)

These criteria were chosen to limit the variance between participants. It was decided to avoid novice drivers, as their driving behaviour may still change over time during the course of the study, which would introduce a confounding variable. By using drivers with at least five years of experience, this issue can be avoided. It was also decided to focus on drivers who drive rather regularly. This is especially for the naturalistic fleets, as higher mileage leads to a larger amount of logged data. The age range was mainly chosen to limit variance.

For TomTom, Leeds and Daimler professional drivers will be used. These drivers are assigned by their company which means that there is hardly any influence on their 'characteristics'.

For each fleet additional criteria can apply, for example the restriction of not using glasses while driving for participants in the Swedish test, where an eye tracker is used.

Detailed requirements

The other requirements of drivers depend upon a number of choices later to be made within the project, such as the hypotheses to be tested, data needed for scaling up, the number of driver styles that will be taken into account, and the number of drivers that can participate in the real world trials. For example, if a limited number of drivers can participate it could be better to have a homogenous group as possible (e.g., only women between 30 and 45)

Some specific participant requirements are:

- Sweden: no specific characteristics that hinder the use of the eye tracker (e.g., the drivers should not wear glasses and should not wear a beard or heavy mascara)
- Sweden: Preferably owners of the same vehicle as used in the test (Volvo V70)
- General: Either all drivers that participate have experience with a green driving application / system or none.

Table 10: Overview of participant recruitment across the fleets

VMC	Fleet #	Responsible	# vehicles	type	Vehicle	# drivers	Specific focus?
F	1	IFFSTAR	10	ND	Car	10	
	2	IFFSTAR	2	Control	Car	40	
D	3	IKA	1	Control	Car	10 Drivers (+2 as Backup)	Focus on young male drivers
	4	BMW	1	Control	Car		
	5	Daimler	1	ND/Control	Truck		
	6	TomTom	10	ND	Truck		
I	7	CRF	4	Control	Car		
NL	8	TomTom	10	ND	LCV		
E	9	CTAG	10	ND	Car		
	10	CTAG	2	Control	Car		
S	11	VTI	1	Control	Car	10	distraction
GB	12	Univ. Leeds	10	ND/Control	Bus	>10	Experience driving with (hybrid) bus

5.4 Driver dropout handling

Driver drop-out is almost unavoidable in longitudinal field trials. Replacement drivers should ideally be recruited for satisfying the designed sample size, providing that it is still before a pre-defined break-up point, beyond which it would not be worth replacing. For example, the break-up point for a 12-month trial could be 6-month, because after this point it would become difficult to adhere to the desired proportion of baseline and treatment duration for the replacement drivers. Considerations for the break-up point also depend on the final decision on trial design, for instance whether the trial is an A-B, A-B-A or A-B-C design.

Driver dropout also imposes an impact on the validity of data. Data contributed by the terminated drivers may still be included in the analysis, depending on the specifications of analysis. For example, a driver participated fully in the baseline (e.g., one month) and first month of the treatment period (e.g., another month), then ceased participation in the trial. The data might still be useful if the analysis is based on system exposure measured by distance driven. On the other hand, inclusion of the data would not be warranted if exposure is gauged by time.

Some drivers might temporarily cease participation for a period of time (i.e., going abroad for three months). Such expected disruption to data collection should be identified and therefore filtered out during the recruitment stage.

Precautions will be taken to prevent driver dropout, and some redundancy will be built into the experimental plan, to take into account that some drivers may miss a minor part of the trial. It is very difficult to make detailed plans for driver dropout handling at this stage of the project, therefore the plan for handing driver dropout will be finalised during the pilot phase.

5.5 Instructions

In SP3 systems developed in the ecoDriver project will be tested in controlled on-road studies and naturalistic driving settings. Different target groups of drivers will be involved in these trials, who all must be provided with clear instructions about what is expected of them and what they may expect of the ecoDriver partners carrying out the specific trial. There are at least two different moments in which the (potential) participant needs to be informed about the study and that is during recruitment and at the start of the study. The instruction may also differ between a controlled study and a naturalistic study.

General information during recruitment

During recruitment of drivers for the real world trials to some extent the objectives of the study should be clear. More importantly it should be clear to them what they can expect (e.g., what is provided by the partners of the ecoDriver project) but also what is expected of them (e.g., filling out questionnaires). The information should be general on what will be expected of them in terms of driving, privacy, if and how they will be rewarded, what the goal of the study is, what the general social impact is etc. At this stage, not all details need to be clear necessarily, but enough for the drivers to know if they want to participate or not.

The experiment

When the drivers have signed up for participation, they will have some idea about the goal of the trials. At this point the drivers should receive as much information as needed about the trial, including to some extent information about the objectives of the trial. The amount of information provided to the drivers about the objectives of the study does not always have to be complete in order to avoid getting the desired behaviour of drivers. When informed about what the researcher expects from the trial, the driver may behave in a way to make that happen, only because he or she knows it is expected. Not filling in all the details of the experiment or even giving misinformation may be required, but should be avoided if possible and a debriefing is needed.

Early in the process, preferably at the first moment after the driver has confirmed participation, s/he should be presented an *informed consent* in which all the aspects related to the trial, privacy of collected data and how they can opt out are described. The driver signs this document to confirm reading and understanding it. This is also good moment to fully explain the details of rewarding, if not very evident or already explained thoroughly during recruitment.

Instructions on how it works

Depending on the system that will be tested, the instruction may be more or less elaborate. If the tested system is an in-vehicle system that is used only during driving (in-trip), instructions can focus on how to use the system. If information is also given before and after the trip (pre- and post-trip), additional instruction is needed on when this will be given, what kind of information the driver may expect, etc. Part of the trials may also consist of training or other activities that are not carried out in the car or are non-driving related. For these parts, special instructions are needed, which will usually be part of the training program itself.

The systems developed within ecoDriver will be completely new to most of the participants of the trials. This means that they will need instruction on how to use them. Depending on the system itself, its complexity and intuitiveness, and the way in which it will be tested (controlled study or naturalistic driving setting) more or less instruction will be needed. In all cases it is important to pilot-test the system with the instruction that will be given during the trial phase.

Individually or in a group

Depending on the targeted group, instructions on how the system works can be done individually or in groups. In controlled studies, participants usually visit a (lab-) location one at a time. The instruction then precedes (a first phase of) the experiment. The instruction can be repeated - If needed - when there is a lot of time between driving in different experimental conditions.

Drivers operating in a fleet context (bus, truck and LCV drivers) can be easiest instructed in a group setting. This can be arranged through management and a group instruction would minimise the cost and/or free time of the drivers. There is a risk however those ideas from some (dominant) people in the group can have its impact on others in the group. This can have a very positive effect, if there is already some engagement, but also a negative effect when a few in the group may be opposed to participation. If the system involves a competitive or cooperative aspect, for example truck drivers cooperating to save as much fuel as possible in a month together, it can be very helpful to give instructions in the group to promote group feelings.

Controlled or naturalistic driving

There will be differences between instructions given for the naturalistic driving trials where drivers are driving alone or controlled studies where an experiment leader is still or can be present all the time. When drivers use the system in their own vehicle (i.e., without an experiment leader), additional instructions on how to respond to failures or strange behaviour of the system must be given. They must also be notified that a check whether data collection is successful will be made which if done in the car only may require them being contacted by a technician that will meet them for a check. In case the check can be done remotely, they may be contacted in case problems occur.

In both situations the participant must be explained how to respond to problems or uncertainties with the system. Intervention of the experiment leaders may influence the results of the study, however continuing with the test when errors occur is also undesirable. The problem with intervention applies especially to studies that last only one or a few sessions. It applies less to longer lasting field studies. On the other hand, in field studies uncorrected errors are a larger problem, since the costs per participant is much higher (e.g., in the error goes undetected lot of data can be lost). In general, it can be said that the longer a driver is participating the more urgent it is to contact the driver on errors and the less problematic intervention is. Clear guidelines for the driver are needed on how to deal with these issues.

Ethics

As described above, there is some tension between providing information about the trials and the influence it may have on the driver's behaviour. It is a common rule in psychological studies (or any experiment for that matter) that is more important to do an ethically sound study than a methodologically good study. Fortunately, the first does not rule out the second. A few aspects must be considered however.

Firstly, all drivers must be participate voluntarily and have the freedom to discontinue at any moment. It is important to make them aware of this. Secondly, deceiving drivers about the true motives of the study is only allowed if it does not harm the participants (no stress or trauma) and can't be avoided. If any misinformation or misguidance is used, a debriefing afterwards is needed. Participants must be given full knowledge of what they are going to encounter however, even if they don't know the true objectives of the study. Lastly, the drivers must also know that the data collected about their behaviour is kept confidential and that published data will not include names or other identifiers. This is the case for all data, not only sensitive data.

Most of the ethical concerns may be communicated to the drivers through the informed consent. A form that will notify them of these issues, which they will sign to confirm they have read and understood it. If there is a review board, the experiment should have their approval. Participants should be notified where they can file complaints. If there is no review board or similar institution, the appeals process must be made clear to the drivers.

5.6 Incentives

If drivers see no benefit, they will not participate in the real world trials. However, drivers may consider a wide range of things as benefits. The novelty of the tested systems or the contact with the research group may be enough for certain drivers to participate. However, the advantage of giving a *real* reward, financially or otherwise, is that it will create more commitment to the test. Commitment is very important for the experiment. If they are not committed, there is a chance that they are not trying their best and perform suboptimal. Without commitment, the chance that they quit before the test is over is much higher too. The conclusion is that incentives are needed. The question is then, which incentives?

Financial reward

The most obvious incentive that can be given is money. In general, money is a good incentive for people to participate. However if people are already highly motivated to participate by other reasons, money may have a counterintuitive effect of lowering motivation. If they are intrinsically motivated because they believe their contribution can have positive impact on the environment, for example, this motivation may actually be devaluated by also giving them money. There are also a few complexities with giving people money. Taxes have to be paid for example, which may on the hand complicate the entire rewarding process unreasonably much and on the other diminish the amount of the reward and the effect it may have.

Non-financial reward

A non-financial reward may have advantages over money. Tax issues are less of a problem (if the value is low enough). Issues with devaluation of other intrinsic motivation are also less strong with non-financial rewards. Non-financial rewards can consist of coupons, gadgets, points that can be exchanged for other benefits (e.g., free-hours, holiday-bonus), etc. In the case of ecoDriver, coupons could consist of refunds for one of the products used in the project (e.g., mobile phone, iPad, navigation system, etc.) or the opportunity to keep the product after it is used in the project. Benefits are easier to give in the context of companies. This can be either company where the (car-) drivers work or bus or truck companies participating in the study.

Timing

To keep drivers motivated throughout the entire test phase it is important to time the rewards correctly. When there is a single instance in which the system will be tested (e.g., controlled study where the driver participates once), the nature of the reward must be made clear before the study, but to keep the driver motivated the reward must be given afterwards. In case the driver participant more frequently or during a longer period, it is can be helpful to give rewards before the entire test phase is over. The rewards should then be directly after finishing essential parts of the test phase (after each ride or after the score for the month is made available). There must always be a reward left to motivate the participants to finish the entire test phase, which means there should be a (special) reward at the end of the entire phase if intermediate rewards are given.

Rewards in the system

Within ecoDriver, systems are developed that try to influence driver behaviour to help them save fuel and reduce emissions by giving feedback. Some of these systems may give rewards for certain changes in behaviour to facilitate the testing of these system and making the test as realistic as possible a real reward can be given to the drivers when the system decides. There should also be a reward for participating in the study independent of their behaviour or response to the system Therefore an approach can be to give a partial reward for participation and an optional additional reward as part of the feedback given by the system.

Bus and Truck drivers

For bus and truck drivers a slightly different situation exists. Their participation in the trials is usually mediated through their manager. It is usually the companies' truck or bus they are driving which means that it is the company or the manager who decides if they participate. This can result in on the hand in motivated drivers, if the manager knows how to communicate it and the company can provide the right incentive through salary, bonuses or other non-financial benefits. It may also mean that the drivers are not interested to participate at all but are merely forced because it is part of their job. In the latter case, special attention must be paid to the real motivation of the drivers.

With payment and distribution of rewards, local (company) rules and methods of conduct and national rules must be taken into account. Working with companies means there are additional rules that must be followed. For instance, bus drivers can't easily be given financial rewards because there are agreements made with the union that if one driver receives special benefits, all drivers should be able to receive it.

Variations/consistencies between test sites
It is planned to keep the reward strategy the same across test sites – either all drivers will be rewarded for eco-friendly driving or none. This way, all drivers are treated equally in principle. It is assumed that cultural and other differences would outweigh differences in incentives anyway, and even paying the same amount of money could potentially have a different experienced value, depending on the buying power and the participant type (student vs. employee). Also, people drive for different time durations, so it is very difficult to be able to make incentives be worth exactly the same across all conditions.

5.7 Test routes

Definition of Test Routes shall propose a set of criteria that characterize different aspects which should be covered by conducting the field trials of SP3.

In order to estimate and combine all partners' ideas for Test Routes, IKA has set up a template for scenario definition. This template helps identifying overlaps of different driving situations which are supposed to be covered not only within field trials (SP3) but also can be used for model simulation (SP2) and driving simulator studies (SP1).

The template covers different aspects of how driving situations can be categorized and described:

- General characterization (e.g., motivation)
- Environmental aspects (e.g., traffic)
- Geographical aspects (e.g., terrain)
- Vehicle and driver related (e.g., type of vehicle)

On this basis, a set of common Test Routes can be derived and proposed to be applied by the different partners and their fleets.

Benefits of collaborative Test Routes
Collaborative Test Routes create a common baseline by combining and gathering different aspects that shall be equal for all partners and all fleets. Although each fleet is located at different places, the definition of certain key features can simplify data analysis and evaluation not only within single fleets but also between different partners.

Disadvantages of collaborative Test Routes

Even if a solid baseline of Test Routes can be established for field trials, all partners are still located at different places with the consequence that different fleets do not drive exactly the same routes. Considering that not only location, but also vehicle types and system integration levels are different among the partners, comparing the results may get difficult.

Suggested Test Routes for ecoDriver
In order to elaborate common route characteristics especially fleet types have to be respected. Controlled fleets using cars for example are capable to cover as many different aspects of driving situations within one Test Route that does not take more than approx. two hours.

On the other hand, these driving cycles appear to be very unlikely when they get applied to a truck fleet. Due to the typical driving cycles of trucks it is recommended to choose a longer Test Route which is mainly located on highways. Similarly, the controlled bus fleet of Leeds is mainly dependent on the current shift plan and local bus routes and therefore receives different instructions than the other partners.

For all controlled fleets it would be best if the amount of other road users is low or medium which might affect timing and planning of the Test Routes and trial conduction. High traffic densities might significantly distort the expected test results. Finally, naturalistic fleets will not receive any driving instructions in order to avoid any disturbances in driving behavior and results. However, in this case a greater focus on short range drives in an urban environment is expected.

Common Test Route definitions and characteristics are summarized below:

<u>Route #1 (Controlled fleet, nomadic, full & aftermarket):</u>

- Environmental: Urban (30%) + country (30%) + highway (40%)[1]
- Terrain: Flat (65%) + hilly (35%)
- Duration: about 90-120 min / about 100 km

<u>Route #2 (Controlled fleets, trucks):</u>

- Environmental: Urban (50%) + country (30%) + highway (20%)[2]
- Terrain: Flat (65%) + hilly (35%)
- Duration: about 3-5 hours / about 200-350 km

<u>Route #3 (Controlled fleets, busses):</u>

- Urban environment of Leeds
- Long driving cycles according to shift plan for about 6 hours (?)

<u>Naturalistic (expected):</u>

- Higher focus on short trips of about 15-45 min / about 5-30 km
- Urban environment

1 Relative amounts spent in environmental areas refer to distance, not time.
2 Distribution changed due to project discussion in Leeds, that non-highway routes can have a greater influence on fuel consumption potential than highway routes

- Daily use

An overview is provided in Table 11. Further specifications can also be found in Deliverable_32 1_v1.doc).

Table 11: Overview of partners and suggested test routes –

Partner	vehicle	System	Suggested Test Route	Link to suggested route
BMW	car	Full	Route #1	
Daimler	truck	Full	Route #2	
CRF	car	Full	Route #1	
TomTom	trucks	after-market	Route #2	
TomTom	LCV	after-market	Route #1 / Route #2	
CTAG	car	Full	Route #1	
CTAG	car	Android	Route #1	
CTAG	car	after-market	Route #1	
VTI	car	Full	Route #1	http://g.co/maps/j8yus
IKA	car	Full	Route #1	
Leeds	busses	after-market	Route #3	
IFSTTAR	car	Full	Route #1	http://goo.gl/maps/VsMC
IFSTTAR	car	Android	Route #1	http://goo.gl/maps/VsMC
IFSTTAR	car	after-market	Route #1	http://goo.gl/maps/VsMC

5.8 Feedback strategies

Feedback strategy procedures are not part of this document and will be treated by the Task Force "Feedback". Results can be inspected in a corresponding Task Force "Feedback" document on SharePoint.

5.9 Observed rides

The controlled trips can either be accompanied by an experimental leader or not accompanied, such that the participant drives on his or her own. If accompanied, the experimental leader can either be in the front passenger seat or in a back seat, and he or she can either talk to the driver or remain silent. Several advantages and disadvantages are connected to those solutions.

Benefits of accompanied rides

There are several advantages with accompanied rides during the controlled drives.

- The experimenter can give directions, such that the participant will not get lost or have to deal with a navigation system.
- The experimenter can make observations during the ride.
- The experimenter can ask relevant questions in "real time".
- The experimenter can be of technical assistance if some system on the car fails.

Taking systematic notes of observations during the ride is simplified when a dedicated observation protocol can be used by the experimenter. It is suggested to develop such a protocol (see further specifications under "Observation Protocol" below).

Asking questions and/or making interviews during the ride will obviously influence the driver; therefore thorough considerations and testing are required before the final procedure regarding this aspect is decided upon.

Disadvantages of accompanied rides

- Having an experimenter in the car may influence the driver's behaviour, such that the external validity is reduced.
- Different experimenters may have a different influence on the driver.
- Having an experimenter accompanying the driver on all rides will strain the project budget more than letting drivers go on their own.

A mix of having some rides accompanied and others not, may, however, add another factor to the equation, which may complicate analyses.

Accompanied rides in ecoDriver

For ecoDriver it was decided that the advantages of the accompanied rides for controlled fleets outweigh the disadvantages. It is important that drivers stick to the route to allow for comparisons across trips, and it is not of advantage if the drivers have to interact with a navigation system in addition to the ecoDriver system. Also, some effects of the ecoDriver system may be quite subtle or not easy to extract from the log data alone, which makes it valuable to have a real time observation going on.

Introducing a mix of observed and unobserved rides is seen as disadvantageous, as it will introduce a potential disturbance factor. The UK fleet with bus drivers is an exception. Here it is thinkable to observe only a selected number of rides, as this will not introduce an extra disturbance factor for a bus driver, especially if the observer is discreet and does not draw attention to him- or herself. To fulfil ethical requirements bus drivers might be informed upon enrolment that some of their rides may be observed.

To sum up, the suggestion for the experimental procedure with respect to accompanied rides is as follows:

- For the **naturalistic fleets** no accompanied rides are required.
- For the **controlled fleets** all trips are accompanied for all fleets and all drivers.
- For the **UK fleet** some of the trips may be accompanied, depending on final negotiation with the bus operator.

Table 12 how the accompanied ride is realised in the different fleet.

Table 12. Description of how the accompanied rides are realised in the different fleets.

Test fleet #	Type	accompanied rides implementation
1 (FR)	Naturalistic	No accompanied rides required.
2 (FR)	Controlled	Accompanied rides for all trips.
3 (DE)	Controlled	Accompanied rides for all trips.
4 (DE)	Controlled	Accompanied rides for all trips.
5 (DE)	Controlled	Accompanied rides for all trips.
6 (DE)	Naturalistic	No accompanied rides required.
7 (IT)	Controlled	Accompanied rides for all trips.
8 (NL)	Naturalistic	No accompanied rides required.
9 (ES)	Naturalistic	No accompanied rides required.
10 (ES)	Controlled	Accompanied rides for all trips.
11 (SE)	Controlled	Accompanied rides for all trips (preference to have an interacting experimenter/observer in the passenger seat, and to conduct short directed interviews when suitable).
12 (UK)	Semi	Accompanied rides for some trips

Observation protocol

An observation protocol will be developed within WP32 for use by the observer who will sit in the car together with the participant. A list with variables requested to be observed exists and will be developed further. Based on this the observer protocol will be programmed on a tablet for easy in-car real time use. It will be tested and refined during the pilot phase.

The current suggestion is to have one pre-trip screen with general information like weather, subject id, and road surface state. On the in-trip screen traffic events like overtaking manoeuvres and road constructions can be logged. Some variables will need to be logged throughout the trip, while others may only be logged for certain parts of the trip (e. g. motorway only). On a post-trip screen general information about the trip can be entered.

For further reading on the observation protocol the reader is referred to relevant WP32-documents.

5.10 Questionnaires

Questionnaires provide a means of collecting demographic variables as well as tapping subjective perception of the support systems. Candidate items include:

- Participant demographics
    - Gender
    - Age
    - Years of holding licence
    - Annual mileage
    - Income band
    - Car ownership + engine size
- Relevant items from the Driver Behaviour Questionnaire (DBQ). For example, the aggressiveness section of the shortened DBQ (Lawton et al, 1997) and the violation section of the original DBQ (Parker et al, 1995).
- Driver Style Questionnaire (DSQ; West et al, 1992)
- Driver acceptance (Unified Theory of Acceptance and Use of Technology, UTAUT; Venkatesh et al, 2003)
- Driver perception (e.g., subjective scoring on photographic scenarios)
- Willingness to pay (Price Sensitivity Meter; van Westendorp, 1976)
- Trust in system and advice (Lee and Moray, 1992)

Timing of questionnaire administration is proposed as follows. Some items do not have to be repeated throughout the series of questionnaires.

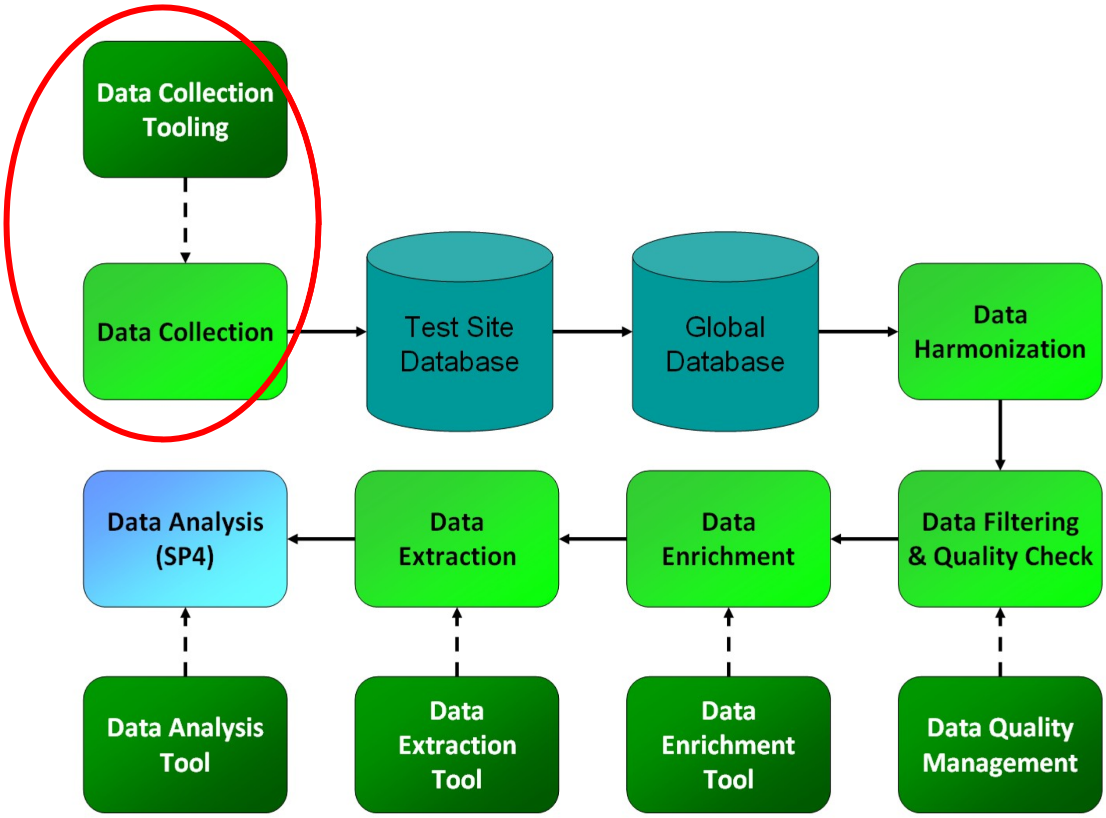
- At the beginning of trial
- At the beginning of treatment phase
- During the treatment phase (frequency depends on the duration)
- At the end of trial

5.11 Sensors and logging equipment

In order to provide SP4 with the suitable data to perform analysis of the ecoDriver solution, the vehicles will have to be equipped with a logging system. This logging system can either be simple logging equipment or a *full* logging system. In this later case, additional sensors will be needed.

In any case, data selected by SP4 and refined within SP3 for both *simple* and *full* logging systems should be harmonized within test sites. This does not mean all provided data has to be in the same format, but all data should answer to a common protocol: type of recorded signal, frequency, etc. Data encryption before database storage is also considered.

Please note that this document is referring to the sensors required for the *full* logging system, not to the sensors required for the *full* ecoDriver system. Some of them might be equal.



Simple logging system

Usage of CAN logging

CAN logging bring a series of advantages over other methods?

- Simple and non-intrusive way to get information
- Collected data can be quite extensive (provided CAN network of the vehicle is already known)
- Cheap method

This logging solution will include CAN information (one or several CAN channels, depending on signals to log and vehicle) and event button.

In some cases the collected data might not be enough due to the fact that some data such as video data is not logged in. Moreover, some vehicles might not have information that might be considered as relevant (e.g., headway, lane position, etc.)

Therefore, CAN – only loggers are considered and suggested to be used as *simple* logging equipment. For those cases where vehicle CAN information is not available, some options are foreseen.

No CAN available

In case CAN network is not available, some fallback solutions are foreseen:

- Usage of GPS data (e.g., ground speed, etc.)
- Usage of additional data acquisition systems (e.g., wired signals)
- Usage of EOBD data
- Usage of nomadic devices as data loggers

Data might be less compete and less precise if compared to CAN data, but for some experiments it might be enough.

Full logging system

The full logging system includes, besides the *simple* logging system, some additional features:

- Video Logging
- Eye Tracker
- Headway Sensor
- Lane detection
- Fuel meter

This additional logging equipment will be synchronized with the *simple* logging equipment.

Data Transmission

Data transmission to the data server can be guaranteed either by remote transfer or manual retrieval.

Remote transfer is specifically recommended for naturalistic driving and involving limited amount of data. Transfer means (3G or GPRS) and strategies can be freely selected by VMCs, as long as data transfer is guaranteed. Data transfer cost is foreseen in some VMCs.

Manual data retrieval is specifically recommended for *full* logging system due to the big amount of data. For some *simple* logging systems it can also be foreseen, but for naturalistic driving it might be more useful to have remote data transmission to avoid vehicle recalls.

Data Enrichment

Data enrichment is not the object of this document, as it will be done offline in the data servers, using map and additional data information.

Equipment

Each partner is free to use the logging equipment they prefer (e.g., have experience, has the lowest cost…). However, minimal data to be collected will be defined within SP4 both for the *simple* logging and for the *full* logging system.

Logging systems overview

The distribution of logging systems across vehicles is described here:

VMC	Fleet #	Responsible	# vehicles	Logging System	Comments
France	1	IFFSTAR	10	Simple	Nomadic Device (gyrometer, accelerometer, magnetometer, GPS), CAN scan using bluetooth (OBDII compliant vehicles), CAN logger (CTAG?)
	2	IFFSTAR	2	Full	Specific CAN logger + front radar + front video + fuel meter
Germany	3	IKA	1	Full	Specific CAN logger + radar + video
	4	BMW	1	Full	Specific CAN logger + radar (internal) + video
	5	Daimler	1	Full	Specific CAN logger + radar (internal) + video
	6	TomTom	tbd	tbd	
Italy	7	CRF	4	Simple	Specific CAN logger system
Netherlands	8	TomTom	tbd	tbd	
Spain	9	CTAG	10	Simple	Specific CAN logger system
	10	CTAG	2	Full / Simple	CAN + video + radar in one vehicle, CAN in second vehicle
Sweden	11	VTI	1	Full	CAN logger + video + eye tracker
UK	12	Univ. Leeds	10	Simple	Nomadic Devices (Smartphone) - more likely to be a TTB solution

5.12 Event button

An event button is simply a button within the reach of the driver (or accompanying experimenter) that can be pressed in case of an event deemed notable, which then leads to a certain action. Different possibilities are:

- A trigger is set in the log data stream, for easy event detection in the data.
- A recording function is activated, such that the driver can leave an audio message of a limited duration.
- Both a trigger is set and a recording is made.

Benefits of an event button

The motivation for an event button with audio recording is that there may be occasions in which the driver makes experiences with the system that he or she wants to convey to the experimental leaders. Being able to make a short recording allows the driver to make the note in temporal proximity to the event, which has the advantage that the driver does not need to memorise the event and then fill in a form or similar in the end of the trip. This also limits the risk that the event is forgotten before it is recorded.

Disadvantages of an event button

On the negative side is the fact that the driver might remind him/herself of being in a study, which pressing the recording button and recording a message while driving might lead to dangerous situations, and that possible technical difficulties will have to be overcome to install the recording function.

Event button in ecoDriver

The event button may have different functions in the naturalistic and in the controlled fleets, and in the latter case there can be a difference between accompanied and unaccompanied trips. The following recommendations are made for the ecoDriver trials:

- For the **naturalistic fleets** it is recommended to create a possibility for the driver to leave a voice recording. This can either be via the nomadic device or via the data logging system. Ideally, the recording should be time stamped such that it can be placed in context with the remaining recordings.
- For the **accompanied controlled trips** it is recommended that the experiment leader has the possibility to set triggers in the log data stream. This will be accompanied by notes on a tablet to explain the triggers.
- For the **unaccompanied controlled trips** it is recommended to let the driver set triggers in the data stream via a button. As the controlled drives are rather short, a verbal or written account can be given in the end of the trip to explain the trigger.

5.13 ecoDriver social network

Social networks are a way to improve the post-trip feedback in order to improve self-learning and self-evaluation. The other important benefit comes from comparisons and/or funny competitions between friends and/or (in our case) test sites that may increase acceptability of maintaining a high level of GhG emissions savings. The idea is to profit from social networking to encourage a beneficial competition for green driving among participants in the trials.

"Perhaps the most important educational element in changing driver behaviour is the positive feedback from taking the desired action. (...) Behavioural theory strongly confirms that unless the individual can see or feel the results of his/her actions—preferably on an immediate and continuous basis—that individual is unlikely to maintain the behaviour over time. The individual components of eco-driving are so small that unless feedback on the collective effort is provided, the driver is unlikely to perceive important changes in fuel economy." (Barkenbus, 2010).

All these findings clarify the interest of using social networks in ecoDriver experiment.

Description of an ecoDriver social network

- ecoDriving scores are published on e.g., a Facebook page;
- confidentiality issues have to be acknowledged: no names or brands are published. Instead, participants will choose a nickname. Drivers must accept these rules beforehand;
- In principle only a e.g., weekly ecoDriving score is published per participant. Thus, every week participants will be tempted to see their score and to compare their achievements to others';
- at that time, each participants will receive advice on how to improve one's score. The advice should take into consideration the full amount of information gathered by ecoDriver logs;
- historical data will also be available for each participant so we will be able to track trends. For example, every week we can have not only the best performer but also the fastest improvement (and potentially also the worst performers and the fastest performance decrease);
- potentially route patterns could also be shared along with the score. For example, some participants might travel mostly on motorways, while others might drive mainly on urban areas. In addition, fleet or vehicle type might also be shared.
- In summary, users will be able to check:
    - the best and worst ecoDriving performers;
    - the fastest improvements and performance decreases;
    - progress and trends for any individual participant;
    - any data can be presented for all participants as a whole or for some cohorts (grouping by fleet or vehicle type, route pattern, …);
    - personalised advice to improve their scores.
- From time to time, meetings between participants might be organized (participation is of course voluntary).

The social networking aspects could be done across sites, initiating a competition between sites. A comment function can lead to discussions on experiences.

Benefits of an ecoDriver social network

Drives people to compete for the best scores, similar to a "peer pressure" effect which could create momentum and a continuous interest in further improvements.

Disadvantages of an ecoDriver social network

This task was not scheduled at the beginning of the project and following both naturalistic driving fleets, and controlled fleets, using such tools may be time consuming. It is not clear how such a process can be implemented. It is also unclear what will be the follow-up the month after the experiment on a test route in the absence of new information.

Confidentiality issues might be raised. Interest might decrease after a while.

Social Networks in ecoDriver

Social network usage may be used for naturalistic fleet for which detailed and up-to-date information on trips made are available. IFSTTAR think that this still needs to be discussed, but we would not recommend using social networks for controlled fleets.

Some discussion points are listed below. Before anything is decided a cost calculation has to be made, and it has to be clarified whether the setup, monitoring and analysis of an ecoDriver social network is feasible within the current budget.

- Opt-in for controlled trials, or even a requirement.
- Upload from nomadic devices.
- Check Facebook "policy" for trials for ecoDriver.

5.14 Focus groups

Focus groups are proposed to be taken place at the end of the trials among participants. More generic questions (i.e., not repeating what would be asked in the questionnaires already) regarding eco driving will be used for facilitating experience exchange.

5.15 Video Confrontation

During a video confrontation a driver is shown a recording of his or her own driving. The clip usually includes an event of special interest for the research question. The driver is asked to think back to that situation and report his or her thoughts, motivations for actions, experiences in the situation and so on.

Benefits of a video confrontation

A video confrontation that occurs in relatively close temporal proximity to the event in question may help gain insight into the driver's thought processes and reasoning within a certain event. It may help explain the motives behind behaviour, which may otherwise be hard to come by. Specifically for ecoDriver it may help us understand why drivers behaved in a certain manner in potentially critical situations.

Disadvantages of a video confrontation

It is quite important to have the video confrontation in close temporal proximity to the drive, which would mean that in a controlled fleet the participant would have to wait for the experimenters to extract the relevant video clips from the latest trip. For the naturalistic fleets, it may be even harder to access and present material in time. Additionally, in the naturalistic fleets drivers will get reminded about being in a study, and may change their behaviour after such a video confrontation. Furthermore, a video confrontation is relatively time consuming, which means that it will drain on resources.

Video Confrontation in ecoDriver

No video confrontations in temporal proximity to the trip will be made within the project. It is suggested, however, that interesting scenes may be presented to possible focus groups consisting of drivers participating in the study. The same clips may even be presented in several different countries, to give participants with different backgrounds the possibility to discuss the same behaviour.

While temporal proximity will be lost, and with some likelihood also the original driver's thoughts and motives, this compromise will give the researchers ample time to extract interesting clips that can be of greater value to have a more general discussion about.

Of course it has to be ascertained that all drivers give their informed consent for their material to be used in such a focus group discussion.

6. Implications for the ecoDriver project

This deliverable provides an overview of the proposed assessment approaches. Hypotheses are developed based on the research questions, and performance indicators are defined for validation of the hypotheses. These will guide through the rest of the work planned in SP4.

This deliverable also presents experimental design for the field trials, covering fleet specifications, participant recruitment, route selection, test procedures, and data collection protocol etc. This will serve as the basis for trial preparation and facilitate trial implementation and management.

Given the different locations and approaches, the sum of all results will provide a better understanding of how drivers use eco-driving systems, how much fuel can be saved, what effects can be expected depending on geographical and climatic circumstances, and which type of system can be expected to lead to which effects. However, the large variation of factors between sites does not allow a fully controlled comparison of all those factors. Therefore, some of the evidence will need to be viewed as indicative or anecdotical, requiring further studies to confirm or reject tentative findings from this project. It will be attempted to collect basic data that allows at least a qualitative comparison of the different test sites.

As with any field study, the studies here are threatened by uncontrollable factors in the environment. These can be changes in traffic regulations or work zones during the time of the study, extreme weather conditions, political or financial occurrences that influence drivers' behaviour, and so on. The geographical and political variation of the test sites makes it unlikely that all tests will be affected similarly, which is a good insurance that at least some of the test sites will produce valid and reliable results.

The results obtained in the field study should be seen as a complement to the simulator studies. While the focus in those studies was on developing an eco-driving system that is as effective as possible, the field studies now give an answer how successful the development was. Most importantly, the success will not only be measured once, but assessed over time for a number of studies. This is very important and often neglected, even though there is evidence that drivers experienced with a support system use it in a different manner than drivers who are novices with respect to the system. Additionally, eco-driving systems have in the past been seen to be neglected over time, which should specifically be addressed and avoided with the ecoDriver system.

The goal of WP41 was to provide a common structure for the field studies conducted within ecoDriver, to make sure that the hypotheses generated can be answered within the study. Striking a balance between a general master plan and considering peculiarities of certain test sites, while at the same time having to incorporate a rather large number of independent variables, like different systems, vehicle types, climate zones, and so on, will necessarily lead to trade-offs between scientific accuracy and structural limitations. Within ecoDriver we will make sure to be honest about the limitations when reporting our results, such that we can be confident that our results will be interpreted correctly. Within the given limitations our aim is to deliver the best possible scientific quality.

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Annex A: Data requirements for emissions modelling with Versit+

This annex specifies the required data for the emission modelling of ecoDriver system.

Data needs (required and nice to have)

Versit+ models "regulated emissions" (CO, NOx, PM10, HC, and some other less important ones) as well as CO2, 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.

Versit+ requires first of all the speed and acceleration of equipped and unequipped vehicles, at 1 Hz frequency. This data is used to determine the driving pattern and calculate from that emission estimates, 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 is required:

- Speed (min 1 Hz frequency, 10 Hz gives better results)
- Acceleration (min 1 Hz frequency, 10 Hz gives better results)
- Slope
- Vehicle type info (collected once per vehicle):
  - For light duty vehicles: vehicle class (ECE vehicle class, i.e., M1, N1), fuel type, emissions class (= EURO emission class), presence (or not) of particulate filters, for vans (N1) also kerb weight.
  - For heavy duty vehicles: vehicle class (bus, rigid truck, truck, i.e., ECE vehicle classes M2, M3, N2, N3), presence (or not) of particulate filters

The following data is nice to know. That is, availability of this data will improve the calculation, and allow to distinguish between effects of the ITS application and effects of other circumstances ("confounding variables"). If this data is not available, then default values can be used:

- Type-approval CO2 value.
- 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).
- 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.
- Engine power.
- Gross vehicle weight (GVW).

Annex B: Scenario description template

General	**No.**	**0**
	Partner	ika example
	Scenario Name	S01_MED01
	Category (DS, SIM, FOT, MED)	MED
	Type (test track, road)	Road
	Duration/length of test session	20 min
Description	**Road Type (urban, motorway, rural)**	urban
	Motivation	investigate driver's behaviour by means of driving and interaction w/ eco system in urban environment
	Characteristic	urban environment w/ traffic lights and stop signs
Environment related	**Other traffic participants Density**	(medium) average urban traffic density, at the least one preceding vehicle
	Environmental conditions	clear
	Day/Night	Day
Route related	**Overall incline slope**	0
	Max incline slope	0.02
	Average speed over scenario	40 kph
	Max speed within scenario	70 kph
	# of curves	20
	Required driving skills	beginner
	Obstacle density	2
Vehicle related	**Vehicle type**	Car
	Vehicle load	70 kg
	Vehicle name and make	RENAULT CLIO III ECO
Driver related	**Level of distraction**	medium
	Driver characteristics and attitude	any
Misc.	**Expected test results**	Drivers will focus more on moving the vehicle through the traffic situation than on paying attention to the eco system

Annex C: Excel file with hypotheses, PIs and comments

A snapshot of the excel file is provided below:

Hypothesis	EMISSIONS	measures needed	PI	Situational variables to enter the analysis	1 IFSTTAR Car Controlled FeDS	2 IFSTTAR Car Naturalistic Android	3 IKA Car Controlled FeDS	4 BMW Car Controlled OEM	5 Daimler Truck Controlled OEM	6a TomTom Truck Naturalistic Aftermarket	6b TomTom Van Naturalistic Aftermarket	7 CRF Cars Controlled OEM	8a TomTom Truck Naturalistic Aftermarket	8b TomTom Van Naturalistic Aftermarket	9 CTAG ICE Car Controlled FeDS	9a CTAG ICE Car Controlled Android	10 CTAG EV car Controlled FeDS	11 VTI Car Controlled FeDS	12 Leeds Bus Controlled Aftermarket
1	Compared to baseline, using ecoDriver system will reduce the average energy consumption (megajoules per km or 100km).	Instant Fuel consumption (CAN or fuelometer)	megajoules per km or 100km	Road type or speed limit (correlated sv variables), traffic density, road condition, hilliness, temperature	Yes	Yes (via OBD	Yes	Yes	Yes	No	No	Yes (aggregated)	No	No	Yes	?	Yes	Yes	?
2	Compared to baseline, using an ecoDriver system will reduce the average fuel consumption (per 100km).	Instant Fuel consumption (CAN or fuelometer)	fuel liters per 100km	Road type or speed limit (correlated sv variables), traffic density, road condition, hilliness, temperature			Yes	Yes	Yes	Yes (FMS/OBDII)	Yes (OBDII)	Yes	Yes (FMS/OBDII)	Yes (OBDII)	Yes	?	NA	Yes	?
3	Compared to baseline, using ecoDriver system will reduce the average CO2 emissions (per km or 100km).	Instant Fuel consumption (CAN or fuelometer)	Grams of CO2 per 100km	Road type or speed limit (correlated sv variables), traffic density, road condition, hilliness, temperature			Testable, if CO2 model available.	Yes, testable.	Testable, if measuring equipmen	Yes (FMS/OBDII)	Yes (OBDII)	yes, testable	Yes (FMS/OBDII)	Yes (OBDII)	Yes	?	NA	Yes	?
4	Compared to baseline, using ecoDriver system will reduce the average NOX emissions (per km or 100km).	Instant Fuel consumption (CAN or fuelometer) + Model to be defined (TNO ?)	Grams of NOX per 100km	Road type or speed limit (correlated sv variables), traffic density, road condition, hilliness, temperature			Not testable, because no NOx model available for vehicle at ika.	No	Testable, if measuring equipment available	Tb.d. (yes, but not planned)	Tb.d. (yes, but not planned)	No	Tb.d. (yes, but not planned)	Tb.d. (yes, but not planned)	Yes, if model available	?	NA	Yes, if model available	?
5	Reductions in fuel consumption and emissions vary across vehicle types	As above	As above	Vehicle type: truck, bus,car,van	No	No	No	No	No	Yes		No	Yes		No	No	No	No	No
6	Reductions in fuel consumption and emissions vary across powertrains	As above	As above	Powertrain type: ICE, hybrid, EV	No	No	No	No	No	No	No	No	No	No	Yes	No	Yes	No	No
7	Reductions in fuel consumption and emissions vary across systems	As above	As above	System type: FeDS, OEM,Nomadic,Aftermarket															
8	Reductions in fuel consumption and emissions vary across systems	As above	As above	HMI type: Haptic v no haptic	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No
9	Using ecoDriver will continuously decrease Energy consumption when penetration rate increases	traffic simulation in SPS	megajoules per km or 100km fuel liters per 100km Grams of CO2 per 100km Grams of NOX per 100km		SPS														

For more information about

ecoDriver project
Prof. Oliver Carsten
University of Leeds (coordinator)
Woodhouse Lane
LS2 9JT Leeds
United Kingdom

O.M.J.Carsten@its.leeds.ac.uk
www.ecodriver-project.eu

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