



iCars Network

D3.3 – Catalogue of impact assessment methods for intelligent vehicle systems

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Abstract	This document includes descriptions of eleven impact assessment methods for intelligent vehicle systems (IVS). The purpose of this draft is to act as a basis and catalyst to the discussion on the use, requirements and detailed contents of such a catalogue.
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1. Introduction

1.1. Intended audience

This document was prepared for experts who develop, assess and deploy intelligent vehicle systems (IVS). It is directed to anyone who is responsible for the impact assessment of IVS or uses the results of the assessment of IVS, such as decision makers, developers and researchers.

The report is a draft version towards a more comprehensive catalogue of impact assessment methods. Consequently, the report will be further developed in the next phases of the work. The purpose of this draft is to act as a basis and catalyst to the discussion on the use, requirements and detailed contents of such a catalogue.

1.2. Structure of the document

Chapter 2 presents and discusses the criteria for impact assessment methods. This deals both with the general criteria, common to all impact areas, and impact area specific criteria.

In chapter 3 the methods identified in the study are listed.

Chapter 4 is the main part of the report including the descriptions of impact assessment methods.

In the chapter 5, the conclusions are made including discussion how well the methods cover different impact assessment areas, and which are the most important areas where new methods should be developed and applied.

1.3. Background and objective of the document

The schematic figure 1 indicates phases in the development of the final Catalogue of impact assessment methods. The current phase is D3.3: Detailed descriptions of the methods in form of 'Draft catalogue of impact assessment methods for intelligent vehicle systems'.

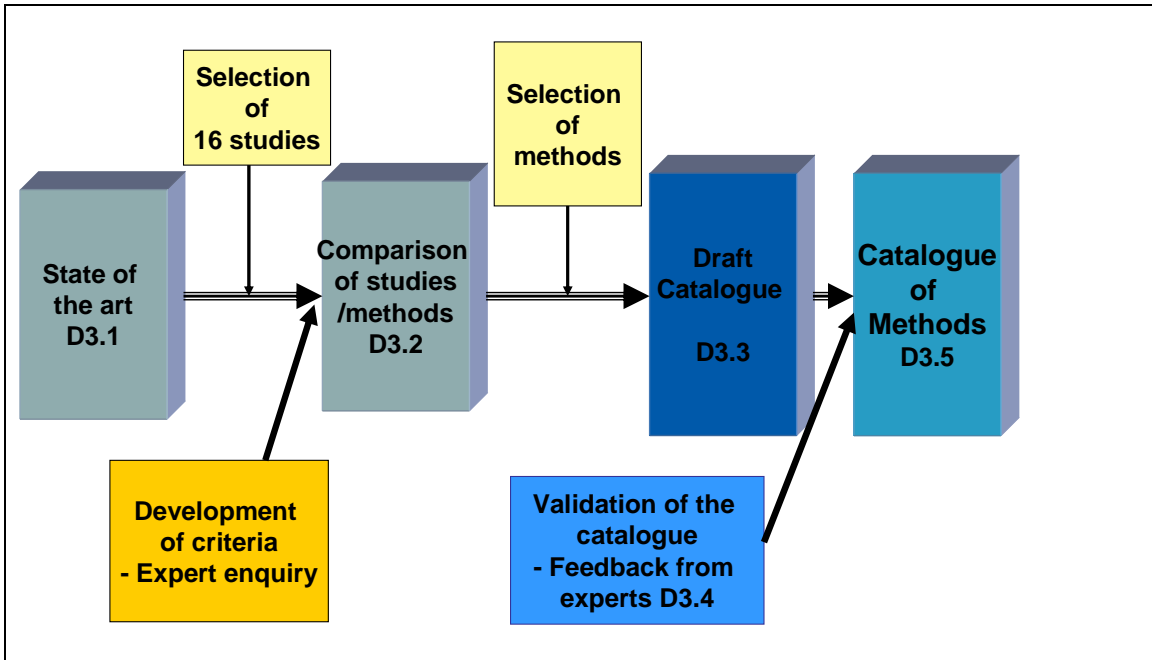


Figure1. Overview of the work in iCars WP3: Impact assessment methods. The final goal is to provide the validated Catalogue of methods.

The objective of this report was to provide the first draft of the impact assessment catalogue. The catalogue includes methods in various uses with regard to impact area, assessment type as well as the life-cycle of the system assessed. The results show the focus and applicability of a selection of methods for different purposes.

The purpose of the document is not only to list different methods but also to characterize a method's application area and the method, including its limitations, by suggesting appropriate assessment criteria and then assessing the methods. The concept of 'method' is defined in the form of a framework we used to describe the methods (in chapter 4). It is acknowledged that the definition is not conclusive or final but more like practical or pragmatic. In addition, the authors are aware that the presentation of the methods without any practical, financial or other real context is theoretical. Furthermore, the selection of a method is always related to a research question either implicitly or explicitly expressed. It is well known that the methods can be applied in a more or less successive manner depending on the resources available. Furthermore, a closer look to the methods reveals that in some cases they overlap – especially, a field study may include several sub-methods and measurements. The methods have

varying levels of details, and there might also be effective combinations of methods.

2. Assessment criteria for a method

2.1. Development of the assessment criteria

The criteria for the assessment and comparison of impact assessment methods were created with support of external specialists in impact assessment. The authors made the first suggestions for the criteria. The criteria grouped in 7, covered common criteria for all impact assessment methods (1), and the six specific impact areas: driver behaviour (2), mobility and travel behaviour (3), traffic system efficiency and traffic flow (4), environment (5), safety (6), socio-economic assessment (7).

The criteria were provided to an expert enquiry in which the experts were requested to provide weights for the suggested criteria (from 5 points for a very important criterion to 0 points for a not needed criterion) and suggest new criteria. The enquiry was sent by e-mail to 82 specialists – 25 replies were received. The group of experts was defined based on participation in previous research projects, publications and personal contacts.

The impact assessment studies identified in the first phase of the work were assessed using the criteria defined. As a result, 17 studies were assessed in detail representing 12 methods. The result of this assessment was utilized in the identification and description of methods for the catalogue.

The common criteria are such that they should be considered in all impact assessment studies. For the six impact areas driver behaviour criteria differ from the other areas. The impacts of an IVS are always mediated via driver behaviour. Therefore, changes in driver behaviour are relevant for all impact areas. Some changes may be measured in driver behaviour and these changes have implications on mobility, efficiency, environment or safety. Historically, driver behaviour studies have often been safety related. On the other hand, socio-economic impact assessment typically uses all other assessments as an input, and differs in this respect from the other methods.

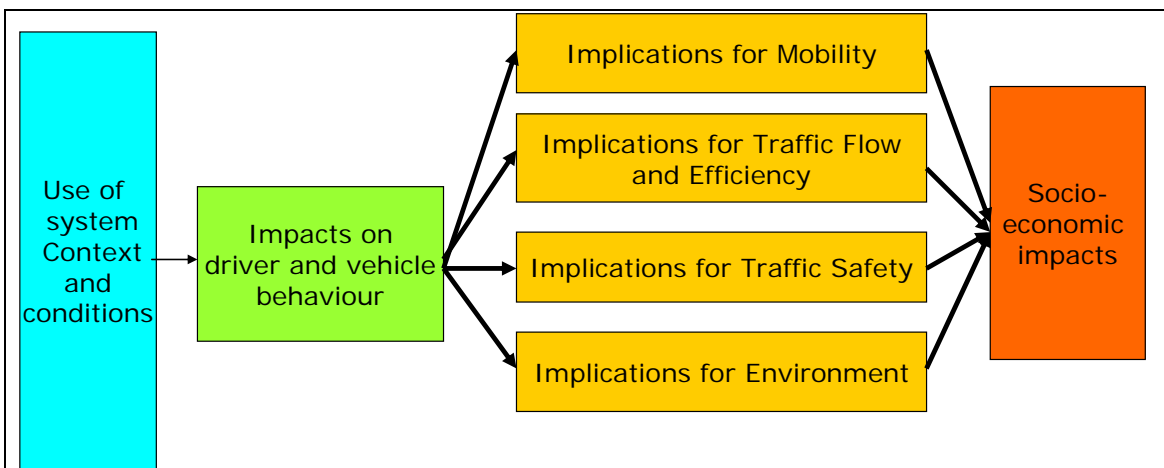


Figure 2. Impacts are mediated via driver behaviour

In the following the impact assessment criteria are presented shortly.

1) Common criteria

The criteria were organized in to the preference order and applied to the selected methods / studies. In all, eleven common criteria for all studies were formulated:

Content validity refers to whether the method measures what it is intended to measure. Completeness and scope of the study is discussed. It should be clarified how well the indicators and measures are motivated, and if all relevant aspects are included.

Ecological validity of a method indicates how well the findings from the study can be generalized or extended to the 'real world' i.e. transport system. How to generalize the results, e.g. from lab to real context or for different locations?

Is the **theoretical background** of the study clearly stated? Is a literature study made? How the theoretical background is motivated and is previous knowledge utilized in the development of the method? The method must enable you to test the hypotheses specified for the impact assessment.

Is the method **reliable** and portable between different applications of ITS?

How well are the **long term effects** covered? What is the time perspective of the study indicated in months? How are novelty effects taken into account, is it possible to identify any stabilisation points in the use and impacts of the system? Are forecasts and system penetrations taken into consideration?

Is the **system specified** in sufficient detail? Are the system interfaces described; is reliability analysis of the system functioning included?

Is the method useful as planning and decision tool for **public authorities**? What is the relevance of the outcome, and is it easy to understand and apply? Does the method produce outputs that relate to social and transport policy goals?

Does the method cover the whole **impact chain** or mechanisms so that the magnitude of the impacts can be explained and understood? Is the process, the impact chain described and are the links identified?

Does the method allow providing **confidence limits or ranges**? Is it easy to provide confidence limits or similar error margins for impact estimates; does the method provide examples of confidence limits? Has sensitivity testing to assumptions been performed?

Is the method useful as planning and decision tool for **manufacturer and consumer**? What is the relevance of the outcome, and is it easy to understand and apply? Does the method give insight into levels of service and utility?

Is the approach optimal for **the phase of system development**? For which phase is the method optimal: idea, plan, prototype, pilot, large-scale demo, full-scale demo? Does the method provide examples or guidance for optimal use?

Does the use of method demand a lot of man power or **human resources**? Are special expertise needed? How efficient are the assessment tools / calculations? Is the method intuitive and easy to apply? Does the method describe the expertise needed; is it possible to indicate in person months.

2) Criteria for driver behaviour

The list of topics which should be covered:

- Is behavioural adaptation considered? (Typically change in time, novelty effects and other than expected behavioural effects)
- Is acceptance of the system included?
- Impacts on tactical decision making and actions (detailed route choice, speed behaviour, proximity, interaction with other road users, detection of road signs etc)
- Impacts on operational decision making and actions (manoeuvring, sensation, feeling, distances to objects in near vicinity)
- Impacts on strategic decision making and actions (planning the journey, modal choice, route choice, driver and vehicle condition)
- Is Human Machine Interface assessment included?
- Is the observational focus (e.g. unobtrusive observation, observation, and self reported behaviour) relevant for the method?
- Is the user definition (e.g. driver, vehicle movements, and traveller) relevant for the method?
- Are driver motivations and attitudes included?

3) Criteria for mobility and travel behaviour

The list of topics which should be covered:

- Impacts on time budget; Total travel time when changing travel modes
- Number of journeys
- Length of journeys
- Travel mode impacts; Alternatives in making the trips
- Impacts on routes?
- Impacts on timing of trip?
- Journey quality: stress, subjective safety, comfort etc
- Impacts on destinations; Impacts on accessibility
- Mobility choice enablers and constraints?
- Are the effects separated for commuting and other trips?
- Total cost to go from A to B

4) Criteria for traffic system efficiency and traffic flow

The list of topics which should be covered:

- Impacts on journey time
- Impacts on congestion / delays
- Impacts on traffic volume
- Impacts on density
- Impacts on speed
- Impacts on time headways
- Impacts on public transport
- Impacts on traffic composition
- Use of simulation-models (extrapolation of data etc)

5) Criteria for environment

The list of topics which should be covered:

- Impacts on fuel consumption
- Impacts on NOX, SO₂, and HC emissions of petrol fuel
- Impacts on CO₂ emissions of petrol fuel
- Impacts on particulate matter (PM) emissions of diesel fuel
- Impacts on noise emissions
- Impacts on the impacts of emissions on environment and health of human beings (toxicity)
- Impacts on further emissions of diesel fuel like lead (Pb), benzene and benzo-a-pyrene
- Impacts on secondary emissions generated by chemical reactions in the atmosphere like ozone
- Does the impact assessment of pollutants differentiate between road types (e.g. urban, non-urban)?
- Does the impact assessment of pollutants differentiate between the structure of vehicle fleet concerning age, installed emission avoiding technology?
- Is traffic intensity considered?
- Does the impact assessment of pollutants differentiate between vehicle types (passenger car, truck)?
- Are weighing factors provided to compare and aggregate toxicity of different emissions used?

6) Criteria for safety

The list of topics which should be covered:

- Impacts on crash risk
- Impacts on crash consequences
- Impacts on exposure
- Impacts by road user
- Is forecasting of accident data done? (extrapolation of data etc)
- Is forecasting of traffic data done? (extrapolation of data etc)
- Impacts by road type
- Impacts by vehicle type
- Impacts by weather conditions
- Impacts by lighting conditions

7) Criteria for socio-economic assessment

The list of topics which should be covered:

- Are all relevant cost components of IVS included (e.g. production, installation and operating costs)?
- Are the main impacts in the field of safety, traffic flow and environmental considered in socio-economic assessment of IVS?
- Are CO2 emission costs considered?
- Are travel time and vehicle operating cost (fuel consumption) savings considered as benefits?
- Are economies of scale in IVS costs considered? (As more and more IVS are installed in vehicles average production costs of IVS will decrease.)
- Does the calculation of accident costs comprise unit cost rates for fatalities, seriously and slightly injured persons?
- Are human costs (pain, grief and suffering) considered?
- Are other emission costs (NOX, PM) considered?
- Are scenarios defined (e.g. "optimistic, realistic, pessimistic") to show a range of results if critical external conditions (e.g. market penetration rate of IVS) are uncertain?
- Is a sensitivity analysis done to identify critical input values for calculation of benefit-cost-ratios?
- Are well established discount rates for calculation of costs and benefits used?
- Are the costs of the whole lifetime of IVS considered? (e.g. initial development and engineering costs, maintenance costs)
- Are changes in congestion costs caused by accidents considered?
- Are costs and benefits analyzed on a stakeholder perspective (e.g. user, manufacturers, insurance companies, public authorities) to integrate distributional impacts of IVS investments (who has advantages and disadvantages)?
- Are the benefits of the whole lifetime of IVS considered?
- Are property damages integrated in cost-unit rates of accidents?
- Is a financial analysis done to show financial impacts of IVS investments on revenues, expenditures and financial cash flow of public authorities?

3. Identification of impact assessment methods

The methods for the assessment and comparison were selected from the sample of studies listed and shortly described in the iCars deliverable D3.1 and D3.2. The studies in the assessment represented all six impact areas (table 1).

Table 1. Number and type of studies for different impact areas.

Impact area	Method (number of studies)
Socio- economy	Cost-benefit studies (2) Multi criteria - analysis (1)
Environment	Emission models (1)
Traffic safety	Statistical study with crash data (1) In-depth study with crash data (1) Expert assessment on safety impacts (1) Combined driving simulator and field test (1)
Driver behaviour	Large scale field study (3) Driving simulator study (2)
Traffic efficiency and traffic flow	Traffic simulation (2)
Mobility	Travel diary and questionnaire (1) Field test on mobility (1)

Next to these studies described in the iCars deliverable D3.1 and D3.2, a few more methods were identified as important methods to be included in the catalogue. These are:

- Small-scale field-test with instrumented vehicles
- Air quality monitoring
- Focus group study

These methods have been included in this catalogue as well.

In the catalogue, the method descriptions are more general than the study assessments in the iCars deliverable D3.1 and D3.2, since the aim of the catalogue is not only aimed at describing the investigated studies, but more the applicability of the methods in general.

Although in our investigation the studies are connected to one impact area as in Table 1, many of the methods can be applied to several impact areas. To clarify this, the impact areas for which the methods could be applied are shown in Table 2. It has to be noted that these are our initial thoughts, and this is open for discussion. For example, a safety assessment with crash data can be used to estimate the indirect effect on traffic flow, by taking into account that accidents may cause congestion, or travel diaries can reveal that the amount of traffic on certain routes could increase, which leads to more exposure and lower traffic safety on these routes. These effects can however only be derived indirectly.

Table 2. Possible impact areas per method, indicated with x. (x) indicates an impact area which is possible but less suitable or indirectly.

	Impact area					
	Socio-economy	Environment	Traffic safety	Driver behaviour	Traffic efficiency and traffic flow	Mobility
Large-scale field study	x	x	x	x	x	x
Small-scale field-test with instrumented vehicles		x	x	x	(x)	(x)
Combined driving simulator and field test		x	x	x	(x)	
Expert assessment (on safety impacts)			x	x		
Safety assessment with Crash Data			x		(x)	
Cost benefit analysis (CBA)	x					
Multi criteria analysis (MCA)	x	x	x	x	x	x
Emission modelling		x				
Air quality monitoring		x				
Focus group study		(x)	(x)	x	(x)	x
Traffic simulation		x	x		x	
Driving simulator studies			x	x	(x)	
Travel diaries			(x)		(x)	x

Furthermore, it will be discussed for which phases in the life cycle of an IVS system the methods are most applicable. The phases identified are: idea; plan; prototype; piloting the system; large-scale demo; and full-scale implementation. The methods will be related to these phases.

4. Description of impact assessment methods

In the following chapters individual methods are described using the framework provided in the Appendix 1.

Driver behaviour

4.1. Driving simulator studies

1 Short description of the method

A driving simulator study is a study in a driving simulator (a car or truck on a fixed location with a simulated traffic environment) in which driver behaviour is studied with a number of test persons, e.g. in different traffic situations or while using new in-vehicle technology.

2 Context of the evaluation

2.1 Phase – lifecycle of the product / Intelligent Vehicle system

A driving simulator study is most suitable for the development and testing phase of new ITS systems, since it can be tested easily and safely. Since the traffic situation can be controlled totally, systems can be tested under specific circumstances. In an early stage of specification and development of an application, e.g. timing, potential impact and parameter settings can be assessed in various conditions and can be used to learn about user behaviour, acceptance, system helpfulness and usability. Setting up the experiment itself already produces new and valuable knowledge on the design of the system.

2.2 Expected outcome, research questions

The outcome is insight in how drivers will behave under different traffic circumstances related to different aspects of the traffic, the system and the driver, to assess timing, potential impact and parameter settings in various conditions and learn about user acceptance, system helpfulness and usability.

Examples of research questions: What are the effects of ACC on driving behaviour and acceptance and how is this determined by individual differences? How does this IVSS influence the workload of the driver? Which HMI is the most suitable?

2.3 Target group of the outcome

Driving simulator experiments are especially useful in an early stage of specification and development of an application, therefore it is mostly suitable for designers and manufacturers of the system. It gives insight in user acceptance and use of the system, which could be used to improve the HMI, or change the system settings e.g. for better traffic efficiency or safety. Also, the marketing strategy could be adapted according to the results, e.g., in [ref Hoedemaeker], it turned out that high speed drivers like the comfort of the system, whereas low speed drivers like the

system's usefulness. In order to get both driver groups into ACC-cars they should be addressed differently.

The results can also be of interest for authorities, e.g. concerning the safety potential of new systems.

2.4 Resources needed

2.4.1 Organisational

A driving simulator experiment requires a medium amount of organisational effort. The equipment, a driving simulator and its software, needs to be adapted for the experiments. Furthermore, participants need to be recruited and the driving simulator tests need to be planned and executed.

2.4.2 Personnel

There are different kinds of personnel expertise needed to perform a driving simulator study. First, expertise in designing driving simulator experiments is needed, concerning the number of participants, number of experiments and conditions of the experiments. Also, the technical equipment and driving simulator software needs to be maintained and adapted for the experiment (to generate the right traffic conditions and to simulate the ITS application, if necessary) by a technician and software engineer. Then there needs to be someone who will recruit and plan the experiments. Also, there needs to be someone who guides the test persons and the experiments, such as a driving instructor and an observer. For the data analysis, statistical and psychological knowledge is needed. Hence usually, there are several persons needed to cover all these expertises.

2.4.3 Technical

For driving simulator experiments, a driving simulator is needed. There are many types of driving simulators, from a very low-cost fixed pc simulator to extremely costly and unique equipment in which all types of movements and forces (e.g. centrifugal in curves) are possible (e.g. Desdemona [ref]). The most used driving simulators use (parts of) a real car and screens surrounding it to visualize the traffic environment. It can either be a fixed-base (non-moving) or a moving-base simulator. A moving base resembles better with real-world driving, since it can e.g. be turned edgewise in curves. Furthermore, special driving simulator software is needed.

An example of a driving simulator from one of the reference studies [ref] is a fixed-base driving simulator of a Volkswagen Golf 4 mock-up with normal controls (including manual transmission). The road and traffic environment are projected on a screen around the car.

2.4.4 Financial

The initial costs for the development and/or purchase of a driving simulator and software are very high. Furthermore, many experts and time are needed for the maintenance and operation of the simulator. Total costs (in person months) of a small driving simulator experiment,

provided that you already have the equipment, can be estimated at 5 to 10 person months

3 Orientation of the method

3.1 Theoretical / empirical; Ex-ante / ex-post

The orientation of the method is empirical, in the sense that a real driver is observed in an as real as possible environment. Usually driving simulator experiments are ex-ante, since new technology is tested first in the simulator before it is tested in the real-world.

3.2 Experimental / natural

A driving simulator study is experimental, since it is carried out in experiments with predefined scenarios. In this way, the exact conditions in which the system needs to be tested can be generated. On the other hand, the aim is that the driver behaviour is as natural as possible, by using a driving simulator and simulated environment which is as close to reality as possible.

3.3 Background: theoretical, practical

The background of a driving simulator study is both theoretical and practical. Theoretical, since the design of the experiments and implementation of the scenarios in the driving simulator software are based on theoretical methods. Also, statistical analysis and psychological aspects have a theoretical background.

The setting-up and execution of the experiments and selection and observing of the participants is mostly practical of nature.

4 Focus

4.1 Driver behaviour

The aim of a driving simulator study is to get insight in the driver behaviour under different circumstances or while using different types of systems.

Driver behavioural aspects that are often considered in driving simulator experiments, are behavioural adaptation, impacts on tactical decision making (speed behaviour, interaction with other road users, detection of road signs etc), impacts on operational decision making (manoeuvring, sensation, distances to objects in near vicinity), driver condition (workload, fatigue), acceptance of the system and Human Machine Interface assessment.

4.2 Traffic flow and efficiency

Traffic flow and efficiency effects are not a direct result of driving simulator experiments, but can be derived from measured driver behavioural parameters such as headways and speed choice. These results can e.g. be used as input for a traffic simulation model to derive more accurate results on traffic flow and efficiency.

4.3 Safety

Safety effects can be derived from surrogate safety parameters, such as proportion of critical time-to-collisions, speed differences, short headways or strong decelerations.

Also, specific and rare dangerous situations can be tested by predefining these situations in the driving simulator scenarios.

5 Description of the method

5.1 Short description of the underlying principles

To set-up a driving simulator experiment, the traffic conditions of the experiments need to be defined and implemented beforehand. A typical driving simulator scenario consists of a certain route with predefined other traffic and a visual surrounding (trees, buildings), which the participant has to drive. His behaviour will be logged, such as speed, position, use of pedals and gear shift etc. A second person will instruct and observe the participant. A participant will usually drive a few routes or scenarios, and the experiment is done with several participants. The logged and observed behaviour will afterwards be analyzed statistically. Also, often the driving simulator experiment is extended with a questionnaire, before and/or after the driving simulator experiment, to get more information about the driving sensation, user acceptance etc. An example of such a questionnaire is the Driving Style Questionnaire from West e.a. (1992) "Decision making, personality and driving style as correlates of individual risk".

The results of the experiment are finally analyzed statistically, in order to determine if the effects are statistically significant.

5.2 Type of assessment

The type of assessment is a simulator assessment, complemented with statistics.

5.3 Process/design

5.3.1 Test persons

A group of test persons is selected. Depending on the purpose of the experiments, they should be chosen with certain characteristics, e.g. concerning age, gender and number of years in the possession of a driving license.

5.3.2 Sample size

The number of test numbers should be large enough to get statistically significant results, usually about 30.

5.3.3 Set-up, design

Each test person will perform a number of experiments or scenarios with varying conditions.

5.3.4 Measuring equipment

There are many types of driving simulators, from a very low-cost fixed pc simulator to extremely costly and unique equipment in which all types of movements and forces (e.g. centrifugal in curves) are possible (e.g. Desdemona [ref]). The most used driving simulators use (parts

of) a real car and screens surrounding it to visualize the traffic environment. This could either be a fixed-base (non-moving) or a moving-base simulator. A moving base resembles better with real-world driving, since it can e.g. be turned edgewise in curves. Furthermore, special driving simulator software is needed.

5.3.5 Data requirements

Measured traffic data can be used to represent a specific traffic situation in the simulator experiments, but also fictive traffic situations can be generated.

5.4 Expertise needed

There are different kinds of personnel expertise needed to perform a driving simulator study. First, expertise in designing driving simulator experiments is needed, concerning the number of participants, number of experiments and conditions of the experiments. Also, the technical equipment and driving simulator software needs to be maintained and adapted for the experiment (to generate the right traffic conditions and to simulate the ITS application, if necessary) by a technician and software engineer. Then there needs to be someone who will recruit and plan the experiments. Also, there needs to be someone who guides the test persons and the experiments, such as a driving instructor and an observer. For the data analysis, statistical and psychological knowledge is needed. Hence usually, there are several persons needed to cover all these expertises.

6 Results:

6.1 Type of output

It gives quantitative results on driver behaviour in terms of speed, acceleration, headway etc. Also confidence limits and can be derived, as well as issues with regard to behavioural adaptation, workload, system helpfulness, usability, comfort and user acceptance.

6.2 Parameters / description

Examples of parameters that can be measured with driving simulator experiments, are:

speed and headway choice, acceleration and deceleration behaviour, maximum braking level, headway (distance to predecessor), use of the gear box (e.g. for fuel efficiency), time to start braking as reaction to a critical event, gap acceptance (size of the gap for merging and overtaking situations), workload (measured e.g. by the 'peripheral detection task', i.e. the number of times that a blinking light in the corner of one's eye is seen, indicated by a pressed button). Also, parameters on safety, environment and traffic flow efficiency can be derived, such as TTC's (Time To Collision), speed variability and capacity (derived from headways and speeds).

Often in an additional questionnaire, more information is gained on issues concerning the feelings of the driver, such as driver motivations and attitudes to the system, acceptance, usefulness and comfort of the system.

7 Restrictions of the method

7.1 Limitations

Both the vehicle behaviour and the traffic in the simulation might not be completely realistic, and the occurring traffic situations are programmed beforehand (no unexpected traffic situation will occur)

Also, people in the driving simulator might react differently than in reality. Furthermore, driving simulator experiments per definition only measure the driver behaviour at the time of the experiment, therefore it does not cover long term effects.

Moreover, it does not cover traffic effects for higher penetration rates.

7.2 Scalability; extension to real world

A driving simulator experience is close to the 'real world' and the participants are normally chosen randomly (or with certain desired attributes), so it is likely that the average driver behaviour (on the short term) in the real-world would resemble the driver behaviour as measured in the driving simulator. However, it is hard to generalize or scale the results.

7.3 Reliability and risks

Reliability of the measured data is high, since the driver behaviour is directly logged during the experiment. There is however a risk that the driver behaviour would be different in reality, or that the simulated traffic is not realistic.

8 Examples of use

Driving simulator study for intelligent cooperative intersection safety system (IRIS) (part of the European research project SAFESPOT)

<http://www.itsineurope.com/index.cfm?do=timetable.paper&paperID=2748>

Feenstra, P.J., Hogema, J.H. (2007). Driving simulator assessment for human factors research. *In Proceedings 6th European Congress and Exhibition on Intelligent Transport Systems and Services*, Aalborg, Denmark.

Driving with Intelligent Vehicles – Driving behaviour with ACC and the acceptance by individual drivers

<http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=881121&isnumber=19061> <http://repository.tudelft.nl/file/164861/135194>

Hoedemaeker, M., Driving with Intelligent Vehicles, Driving behaviour with Adaptive Cruise Control and the acceptance by individual drivers. TRAIL Thesis Series T99/6. Delft University Press. Delft, The Netherlands. 1999.

Minderhoud, M.M., Supported Driving: Impacts on Motorway Traffic Flow. TRAIL Thesis Series T99/4. Delft University Press. Delft, The Netherlands. 1999.

Driver behaviour

4.2. Focus group study

1 Short description of the method

A focus group is a form of qualitative research in which a group of people are asked about their attitude towards a product, service, concept, advertisement, idea, or packaging. Questions are asked in an interactive group setting where participants are free to talk with other group members (2).

2 Context of the evaluation

2.1 Phase – lifecycle of the product / Intelligent Vehicle system

A focus group study for IVSS evaluations is most suitable to test existing systems which were already in the possession of the group members for some time. Ideal is if the participants already used the systems a considerable time before they were chosen to participate in the focus group study. The product should then already be on the market. It is also possible in an earlier phase, when the system is made available to the participants before it is on the market.

2.2 Expected outcome, research questions

The expected outcome is the attitude and self-reported behaviour of the focus group members in relation to the IVS of study. The focus group discussion will be guided by research questions which were defined beforehand. In (1) concerning a focus group study on the ESC system, the following research questions were discussed:

- Is the driver aware of having an ESC system in the car?
- What knowledge and practical experience does the driver have considering handling and use of the ESC system?
- Is the driver aware of any change in his/her driving behaviour as a consequence of the ESC system?
- What is the perceived use and acceptance of the ESC system?

2.3 Target group of the outcome (public authorities, manufacturers etc.)

Often, the target group of a focus study are marketeers. In the world of marketing, focus groups are seen as an important tool for acquiring feedback regarding new products, as well as various topics. In particular, focus groups allow companies wishing to develop, package, name, or test market a new product, to discuss, view, and/or test the new product before it is made available to the public. This can provide invaluable information about the potential market acceptance of the product (2).

It can also be useful for manufacturer and consumer, since acceptance and usability of the system or HMI design can be studied.

The attitude and acceptance of the system reported by the (long-term) users could furthermore be important information for planning and decision on implementation of the system for public authorities.

2.4 Resources needed

2.4.1 Organisational

No large organisational efforts required. The focus group participants need to be recruited and a meeting should be prepared with the focus group. It can be tough to get the focus group together.

2.4.2 Personnel

One or two moderators are needed to lead the discussions. An observer is also useful, to make notes and observe the behaviour of the participants. Beforehand and afterwards, one or two persons are needed to recruit the participants, prepare the meeting and analyse the discussion.

2.4.3 Technical

No technical resources needed.

2.4.4 Financial

Focus group studies are low in costs; there is little time needed and there are no hardware costs.

Focus group studies are less expensive than other forms of traditional marketing research. There can be significant costs however: if a product is to be marketed on a nationwide basis, it would be critical to gather respondents from various locales throughout the country since attitudes may vary due to geographical considerations. This would require a considerable expenditure in travel and lodging expenses. Additionally, the site of a traditional focus group may or may not be in a locale convenient to a specific client, so client representatives may have to incur travel and lodging expenses as well (2).

3 Orientation of the method

3.1 Theoretical / empirical; Ex-ante / ex-post

A focus group study is empirical: the discussion is based on empirical experiences of the focus group participants. Since they have used the system already, the study is ex-post.

3.2 Experimental / natural

A focus group study can be both experimental and natural. Experimental, when they used the system in a FOT and to participate in the focus group. It is natural when they already owned and used the system before participating in the focus group, such that they were not really testing the system beforehand and behaving 100% natural. The latter was the case in (1).

3.3 Background: theoretical, practical

The background of a focus group study is practical: it concerns research question formulation, group discussion leading and discussion analysis.

4 Focus (choose the relevant ones and utilize the criteria from expert enquiry)

4.1 Driver behaviour

A focus group study is very suitable to get insight in driver behaviour and attitudes, since the focus group consists of drivers who report on their driving behaviour. Driver behavioural topics suitable for a focus group study, are behavioural adaptation as a consequence of the system, acceptance of the system, impacts on tactical, operational and strategic decision making and actions, Human Machine Interface assessment and driver motivations and attitudes.

Examples of these issues, which were discussed in the focus group study of (1):

- Behavioural adaptation: Is the driver aware of any change in his/her driving behaviour as a consequence of the ESC system? No, they did not notice any change in their driving behaviour.
- What is the perceived use and acceptance of the ESC system? The acceptance was total; all participants thought that this system (or driver support systems in general) is a good idea.
- Impacts on tactical decision: They all claimed they would make the same choices with or without the system concerning for example speed, turning and overtaking.
- Impacts on operational decision: they said their driving style and driving choices were made according to the prevailing road and traffic conditions as well as their perception of their own driving skill, and they claimed they did not change their driving behaviour when the ESC lamp indicated an intervention.
- Human Machine Interface assessment: All participants thought the ESC system has a good interaction design and that a blinking lamp is sufficient for communicating that the system is active. Also, the lamp is lit when the car is started to indicate that the system is in function. This was also considered good and adequate.
- Driver motivations and attitudes: None of the participants claimed they asked for the system when they bought the car. It was "something that was just there" and they hadn't thought of asking for it in particular. However, the acceptance of the ESC system was total. They all thought that they were helped by the system in their driving.

5 Description of the method

5.1 Short description of the underlying principles

A focus group is a form of qualitative research in which a group of people are asked about their attitude towards a product, service, concept, advertisement, idea, or packaging. Questions are asked in an interactive group setting where participants are free to talk with other group members(2).

Using focus groups to evaluate a system is a very efficient way to get user feedback and gauge initial reactions to a design. Focus groups are also good at discovering how the system being tested differs from the user's current expectations (4).

The use of focus groups has steadily evolved over time and is becoming increasingly widespread.

Group discussion produces data and insights that would be less accessible without interaction found in a group setting—listening to others' verbalized experiences stimulates memories, ideas, and experiences in participants. This is also known as the group effect where group members engage in "a kind of 'chaining' or 'cascading' effect; talk links to, or tumbles out of, the topics and expressions preceding it" (Lindlof & Taylor, 2002, p. 182) (3)

Group members discover a common language to describe similar experiences. This enables the capture of a form of "native language" or "vernacular speech" to understand the situation (2)

Focus groups provide two major benefits. First, they are less expensive than conducting interviews with the same number of people. Second, they rely on group interaction to trigger memories that may not come up during interviews. Where task analysis often discovers the standard way people interact with information systems, focus groups can bring out exceptions to the rules. These exceptions are often very important interactions that users simply do not think of in one-on-one sessions (3).

5.2 Type of assessment

Discussion with focus group

It concerns self reported behaviour. Also, the participants could influence each other, since they discuss together.

5.3 Process/design

5.3.1 Test persons

The test persons need to have considerable experience with the system of study. The period of which the participants of the focus group of (1) had owned their present car with ESC varied from 4 months to 4 years (3 of the 5 participants at least 3 years). Other characteristics can be chosen randomly or with certain desired distributions, e.g. concerning age, gender, income etc.

5.3.2 Sample size

A focus group usually consists of 6 to about 12 persons, but smaller is also possible, e.g. in a so-called mini focus groups - groups are composed of four or five members. Also, several focus group meetings with more groups can be arranged. Conducting only a single focus group can be misleading, as some groups are affected by "group-think"

or may simply have irregular views. For this reason, it is better to evaluate at least two groups for any one project.

5.3.3 Set-up, design

A focus group on IVS consists of persons (drivers) which have experience with the system of study. They will meet and discuss certain issues, guided by a focus group leader, who prepared the discussion and research questions. The focus group leader writes up the impressions and comments of the groups and recommends areas for improvement.

In focus groups, researchers (and the moderators and observers of the focus group, if the researcher is not there) are not detached observers but always participants.

In (1), the process was as follows:

A focus group of 5 random persons driving with an Audi A4 with ESC was chosen. They received a monetary compensation of 500 sek. 5 research questions were discussed during the focus group meeting (the purpose was revealed later during the discussion).

Variants of focus groups include:

- Two-way focus group - one focus group watches another focus group and discusses the observed interactions and conclusion
- Dual moderator focus group - one moderator ensures the session progresses smoothly, while another ensures that all the topics are covered
- Dueling moderator focus group - two moderators deliberately take opposite sides on the issue under discussion
- Respondent moderator focus group - one or more of the respondents are asked to act as the moderator temporarily
- Client participant focus groups - one or more client representatives participate in the discussion, either covertly or overtly
- Teleconference focus groups - telephone network is used
- Online focus groups - computers connected via the internet are used

5.3.4 Measuring equipment

No measuring equipment needed.

5.3.5 Data requirements

No data requirements.

5.4 Expertise needed

For the preparation and recruiting of the participants, basic organisational skills are required. Furthermore, knowledge of the system and the research questions are needed in order to prepare and lead the discussion properly. The observers and moderators need to be highly trained in

observing and interview techniques. Some basic analysing skills are needed for the analysis and drawing conclusions afterwards.

6 Results

6.1 Type of output

The type of output is a report with a description and analysis of the focus group meeting and conclusions.

6.2 Parameters / description

The output parameters are the discussed research questions and the answers on these in written form. For example, in (1), the following 4 research questions were discussed during the meeting:

- Is the driver aware of having an SC system in the car?
- What knowledge and practical experience does the driver have considering handling and use of the ESC system?
- Is the driver aware of any change in his/her driving behaviour as a consequence of the ESC system?
- What is the perceived use and acceptance of the ESC system?

7 Restrictions of the method

7.1 Limitations

A focus group study does not provide quantitative or objective measures (this could e.g. be supplemented with a driving simulator study). Also, it only considers self-reported behaviour.

In (1), the focus group study rendered a brief insight into how normal drivers perceive the ESC system in their cars. It hence considered only self-reported behaviour of subjective measures. Also, the focus group was quit small, only 5 persons, which will probably not be statistical reliable.

In (2), some more limitations are mentioned:

- The researcher has less control over a group than a one-on-one interview, and thus time can be lost on issues irrelevant to the topic;
- The data is tough to analyze because the talking is in reaction to the comments of other group members;
- Observers/ moderators need to be highly trained,
- Groups are quite variable and can be tough to get together.
- Focus groups are "One shot case studies", unless they are repeated (6).
- Focus groups can create severe issues of external validity, especially the reactive effects of the testing arrangement (7).

About the latter issue, if the focus groups are held in a laboratory setting with a moderator who is a professor and the recording instrument is obtrusive, the participants may either hold back on their responses and/or try to answer the moderator's questions with answers the participants feel that the moderator wants to hear.

Another issue with the focus group setting is the lack of anonymity. With all of the other participants, there can not be any guarantee of confidentiality.

7.2 Scalability; extension to real world

As long as the design of the focus study and the composition of the participants provides the constraints for reliable results, the results are easily extended to the real-world, since the participants are representatives of the 'real-world' and have used the system in the real-world already.

Long-term effects can be covered when the participants used the system for a considerable time. In (1), the period of which the participants of the focus group had owned their present car with ESC varied from 4 months to 4 years (3 of the 5 participants at least 3 years).

Concerning scalability, it would be critical to gather respondents from various locales throughout the country since attitudes may vary due to geographical considerations.

7.3 Reliability and risks

A fundamental difficulty with focus groups (and other forms of qualitative research) is the issue of observer dependency: the results obtained are influenced by the researcher, raising questions of validity. Indeed, the design of the focus group study (e.g. respondent selection, the questions asked, how they are phrased, how they are posed, in what setting, by whom, and so on) affects the answers obtained from respondents. In focus groups, researchers (and the moderators and observers of the focus group, if the researcher is not there) are not detached observers but always participants. Researchers must take this into account when making their analysis (Based on 8)

Furthermore, it is not easy to provide confidence limits or similar error margins for impact estimates, since only subjective information is obtained.

Moreover, the number of members of a focus group is not large enough to be a representative sample of a population; thus, the data obtained from the groups is not necessarily representative of the whole population, unlike the data of opinion polls. (4)

However, (2) claims that focus groups have a high apparent validity - since the idea is easy to understand, the results are believable.

8 Examples of use

1. A test method for evaluating safety aspects of ESC equipped passenger cars – A prototype proposal (Mattias Hjort e.a., VTI)
http://www.vti.se/templates/Report____2797.aspx?reportid=11342

Additional references:

2. From Wikipedia, the free encyclopedia
http://en.wikipedia.org/wiki/Focus_group

3. Lindlof, T. R., & Taylor, B. C. (2002). *Qualitative Communication Research Methods*, 2nd Edition. Thousand Oaks, CA: Sage.
4. <http://www.usabilityfirst.com/methods/focus.txt>
5. Rushkoff, Douglas, *Get back in the box : innovation from the inside out*, New York : Collins, 2005
6. Nachmais, Chava Frankfort; Nachmais, David. 2008. *Research methods in the Social Sciences: Seventh Edition* New York, NY: Worth Publishers
7. Campbell, Donald T., Stanley, Juilian C. *Experimental and Quasi-Experimental Designs for Research*. Chicago, IL: Rand McNally
8. Tjaco H. Walvis (2003), "Avoiding advertising research disaster: Advertising and the uncertainty principle", [*Journal of Brand Management*](#), Vol. 10, No. 6, pp. 403-409).

Driver behaviour

4.3. Large-scale field study

1 Short description of the method

A field study involves observing drivers while they are using the system. No specific situations are provoked, and the users just have to drive normally. The observation can be intrusive or not and the data collection can be done in the same points (control points, the same for every observed car) or during a time period of normal driving (different itinerary and habits for each participant). The objective is to measure the impacts in large-scale use with a considerable amount of test users to get statistically significant results.

2 Context of the evaluation

2.1 Phase – lifecycle of the product / Intelligent Vehicle system

A field study is typically done in the last phases of lifecycle, as the system must be installed in a real car. It can be carried out in the pilot, large-scale demo and full-scale implementation phases.

Carrying out a field test in previous phases of the lifecycle is difficult because of the high number of cars with the system needed in order to have results enabling statistically reliable conclusions. So it would be very expensive to build several prototypes to do a field test in a previous phase of the lifecycle.

2.2 Expected outcome, research questions

The expected outcomes are the impacts on driver behaviour indicated in terms of percent changes or absolute measures, when having the new ITS system. Usually, the driver behaviour indicators such as mean speed or similar data will be monitored. However, a lot of parameters can be measured, and the outcome can be very different for each study.

2.3 Target group of the outcome (public authorities, manufacturers etc.)

One key target is the public authorities because the system must be in the last phases of its lifecycle requiring decisions on regulation, incentives etc. It can be also useful for the manufacturers in order to get reliable information about the system performance in real situations and how the drivers accept and use it (do they use it always? Do they use all the functionalities?).

2.4 Resources needed

2.4.1 Organisational

It is necessary to find the required number of drivers with the system installed in their cars, or to recruit the test persons. Depending on the system it may need to be installed in the cars and, if the observation is going to be non-intrusive (e.g. speed measuring with fixed radar) is necessary to find the control points and get permission from the authorities to carry out the data collection.

2.4.2 Personnel

In the installation the systems and measurement equipments, mechanics and electronics engineers will be needed. Cooperation with system designers, service providers and research scientists is needed.

2.4.3 Technical

Sensors and measuring instruments are needed. If the system is not on the market yet, it would also be necessary to install the system in some cars. Also some additional tools or software packages may be used to analyse the data (e.g. excel, SPSS, Matlab).

2.4.4 Financial

It can be quite costly, as many cars need to be equipped and you may have to pay the participants and install the system in their cars or even lend them cars with the system installed in.

3 Orientation of the method

3.1 Theoretical / empirical; Ex-ante / ex-post

The orientation is empirical and ex-post.

3.2 Experimental / natural

The method is natural but in some cases an experimental design is applied.

3.3 Background

The use of field studies relies on the idea that it is essential to get experience about the real use of the systems in real context to be able to verify the potential impacts found in more lab like environments (driving simulators, expert assessments etc).

4 Focus

4.1 driver behaviour

The driver behaviour is inferred from the measurements taken. The measurements of changes in the strategic level often have to focus on, but there can be a lot of information about changes at the tactical level. Usually, a data logger is installed in the test vehicles to record all the data. This data itself can define quite well the driver. The impacts on the strategic level can be assessed using travel diaries and questionnaires.

Depending on the type of system, different parameters can be used to determine the behaviour. For instance, the lateral position is essential in a Lane Departure Warning System, but it will not seem so interesting in a speed limiter (even if it can provide useful information or help to find out unexpected behavioural changes). Speed is an essential parameter to describe the changes in driver behaviour and should always be included in the evaluation.

This objective data can be completed with subjective one, which can be collected through a questionnaire or an interview. The drivers can be asked about their opinion and feeling about the system characteristics so

the acceptability and usability of the system can be assessed. Depending on the system a workload test could be useful, too. However, to minimize the measurement efforts loading and influencing the test drivers is appreciated.

4.2 traffic flow and efficiency

The impact on traffic flow can be inferred via crudely extrapolating the changes in the driver level to the whole traffic flow assuming different vehicle flow equipment levels.

4.3 Traffic safety

The impact on traffic safety can be inferred from measures like mean speed or headway distance, as there are studies which link the changes in these parameters with crash risk or injuries severity in case of accident. Traffic safety can also be measured with the help of serious traffic conflicts, also called near accidents. The direct measurement of safety in terms of accidents and their victims is not possible in field studies, unless the field studies are extremely large and long-lasting.

Concerning the safety criteria from chapter 2.1, they can be taken into account in a large-scale field study as follows:

- Impacts on crash risk: higher mean speed indicates a higher crash risk. Also serious traffic conflicts can be studied, which can be evaluated with surrogate safety measures such as Time To Collision.
- Impacts on crash consequences: also related to mean speed and speed just before a collision or serious traffic conflict.
- Impacts on exposure: derived from travel diaries
- Impacts by road user: can be derived for different user groups participating in the field study
- Forecasting of traffic data: usually not done in a field study
- Forecasting of accident data: usually not done in a field study
- Impacts by road type: can be derived from the loggings of the instrumented vehicles, by using map-matching on the logged positions to find the corresponding road types.
- Impacts by vehicle type: can be derived when different vehicle types have been used in the field study, and if each group of vehicle types is large enough for statistical significance.
- Impacts by weather conditions: can be determined by adding weather variables to the data loggings of the vehicles, e.g. from rain and temperature of weather stations nearby.
- Impacts by lighting conditions: can be assessed by adding lighting conditions (e.g. sunset times) to the data loggings of the vehicles

4.4 Environment

The emissions of the cars can be derived from detailed measurements of speeds, accelerations and gear. Also, it can be measured directly from the exhaust with special sensors installed in the car, but this is expensive and deriving it from logged speeds etc. is generally accurate enough.

5 Description of the method

5.1 Short description of the underlying principles

The drivers are supposed to drive normally while they are participating in the study, so the data will show how drivers use the system and how their behaviour changes because of it.

The possibility to generalize the results will be better as the sample is well chosen and really represents the real population. If the measure is non-intrusive and the drivers don't know they are being observed the data is supposed to be even more applicable.

5.2 Type of assessment (desktop, lab, simulator, field, statistics)

Field study.

5.3 Process/design

5.3.1 Test persons

The sample should be also as similar as possible to the population which is intended to be evaluated, so in most cases a heterogeneous sample is preferred (i.e. wide age range, different years of driving licence possession and kilometres driven, etc.).

5.3.2 Sample size

The more people participating, the more reliable and transferable the results tend to be. It depends also on other design factors as how many groups it would be. For instance there can be a control group (i.e. without any system) and some groups with different systems or different versions of the system. There can be also several groups for each type of car. The sample must be big enough to get statistically significant results. Taking into consideration that typically the impacts are small, the sample size must be considerable. The definition of the research unit is to be considered - typically several hundreds relevant situations (a relevant incident or behavioural change on a road section) must be included.

5.3.3 Set-up, design

First, it is necessary to decide whether it would be a comparative or absolute study. If the objective is just to measure some parameters about how the drivers use the system (e.g. how often they use it) it would be an "absolute" study.

On the other hand, if the objective is to compare how the behaviour changes because of the system, then it would be a comparative study and it will be necessary to split the participants in two groups with similar characteristics, or a before and after study with the same group. In long follow-up studies a control group in before after design is need to control the seasonal variation.

The next step would be define which data is going to be measured and how. Mainly, we can divide the measuring in intrusive and non-intrusive. Intrusive measuring implies installing a logger system in the car in order to get the data from it. Non-intrusive measuring is made

with a device placed outside the car (e.g. fixed speed radar by the road side).

5.3.4 Measuring or technical equipment

The required equipment is composed of the cars (which can be owned by the drivers or not) and the measuring equipments. Depending on what is intended to be measured, this can be only a small computer installed in the car or several sensors both in and outside the car.

5.3.5 Data requirements

Required background data are the profile of each driver and car. It can be also useful information about the roads where they usually drive.

5.4 Expertise needed

Transport system, driver behaviour and statistics as well as data processing and analysis expertise is needed. It would be desirable to have also expertise in the ITS system which is going to be studied.

6 Results

6.1 Type of output

The output is objective driving parameters as mean speed, headway or similar. The data on system use (how the drivers use it, how often, in which situations,...) must be related with the behavioural data. In addition user acceptance results will be provided.

6.2 Parameters / description

In theory almost every parameter in a car can be measured, from the speed to the seatbelt usage. Typically, the most interesting parameters are the speed and the ones related with the system usage, which will depend on the system nature and functionalities. Some parameters which can be used to determine driver behaviour can be:

- Speed: It is the most used parameter as it depends directly on driver's decisions. Drivers usually pay much attention to their speed and they can control it very easily, so this parameter is directly linked with driver's intentions. Moreover, is easy to measure. Mean speed and standard deviation of speeds are the most frequently used parameters.
- Headway: This is also a parameter which usually drivers focus on, so it is linked to their conscientious behaviour. It can be measured easily if the car has a radar installed (e.g. in cars with ACC). The proportion of short headways or the headway distribution as such are often used to describe changes in behaviour.
- Steering behaviour parameters: The parameters related to the steering behaviour are also closely related to the driver performance, but they are usually difficult to evaluate.
- Lane lateral position: Number of unintentional lane border crossings, and time to lane crossing are some parameters used in studies.

- Accelerations: The measured accelerations can provide information about how hard or smooth is the driving. The proportion and number of very strong accelerations are often used. The number of instances of very strong jerks (first derivative of acceleration) is used as an indicator of serious conflicts.
- Fuel consumption: This is an example of a parameter which usually is not controlled by the driver, but can help to determine how the driving was.
- Traffic conflicts: The number of serious conflicts is regarded as being approximately proportional to the number of crashes of similar type. The ratio between crashes and serious crashes reported by the police varies by crash type. Usually these are recorded manually by observers in the car or by the road side, but increasingly jerks from data logger data (see accelerations) are being used.

Furthermore, if a questionnaire is used, there can be subjective data like how useful is the system for the drivers or how they think their behaviour is affected by it.

7 Restrictions of the method

7.1 Limitations

The main limitation is that it is needed to have a high number of cars with the system installed in order to have good results.

Moreover, if the participants know their data is going to be recorded, they may not behave normally even if they are told to drive like they always do.

7.2 Scalability; extension to real world

It is real world already. But if the system is very new, the results can be affected by the "learning effect".

7.3 Reliability and risks

The reliability is very high if the sample is correctly chosen.

8 Examples of use

1. Mazzae E. et al. (2001). NHTSA Light Vehicle Antilock Brake System Research Program Task 7.1: Examination of ABS-Related Driver Behavioral Adaptation – License Plate Study. <http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/NRD/Multimedia/PDFs/VRTC/ca/capubs/abs71.pdf>

The objective of this study is to find out if there is a speed increase in drivers using an ABS-equipped car. The speed of the cars was measured in several places, daylight and road conditions. The measuring is unobtrusive, done with a laser sensor. Using a camera, the license plate is also recorded. Searching the plate in a database, several data about the car is found (like if it is equipped with an ABS system or not). The results showed there is not a speed change due to

the these system. Almost 10000 measures where taken, from which over 7500 where valid.

2. TAC SafeCar Project. On-Road Evaluation of Intelligent Speed Adaptation, Following Distance Warning and Seatbelt Reminder Systems: Full Report

In this study, 15 cars where modified to implement four ITS systems. Then, this cars where lent to 15 people who drove them with and without the systems activated for a total of 16500 Km. There was also a control group of 8 people. The main results were related to the speed behaviour (mean speed, percentage of time above the speed limit,...) and headway, but there were also other parameters, e.g. related to the seatbelt or fuel consumption and questionnaires and interviews in order to get subjective data. Furthermore, some safety issues were evaluated indirectly using the mean speed changes observed.

3. Hjalmdahl, M. (2004). In-vehicle speed adaptation. On the effectiveness of a voluntary system (Doctoral dissertation).

The study observed the behaviour of 284 drivers who had a voluntary accelerator pedal installed in their cars. They drove with the system inactive for a month and then it was activated for 11 months more. The speed was recorded with a data logger installed in the car, there were also behavioural observations by two people who were inside the car with the driver and an attitude survey.

4. FESTA Handbook (2008). FESTA (Field operational test support Action) consortium. European Commission DG Information Society an Media, 7th Framework Programme.

Driver behaviour

4.4. Small-scale field-test with instrumented vehicles

1 Short description of the method

A small-scale field-test with instrumented vehicles field study involves observing drivers while they are using the system, as a large-scale field study, only the number of participants is much smaller and the duration of the test period is much shorter. The users just have to drive normally, but specific situations can be provoked. A small-scale field test is usually performed to study a very specific research question in practice. The instrumented vehicles can be highly equipped with logging devices and sensors to perform accurate measurements. Often, test users' own cars are not used in the tests but an instrumented car designed for research purposes.

2 Context of the evaluation

2.1 Phase – lifecycle of the product / Intelligent Vehicle system

A small-scale field-test with instrumented vehicles can be done when there exist at least a prototype of the system, as the system must be installed in a real car. It is usually performed before the large-scale demo and full-scale implementation phases, to test the system or sub-system, traffic safety and driver behaviour with the system, or to be able to tune the system better. There is no need for a high number of participants, however, the more participants, the more reliable the results.

2.2 Expected outcome, research questions

The expected outcome is a qualitative and quantitative description of the change in the users' driving when using the new ITS system, and insight for further development of the ITS system.

2.3 Target group of the outcome (public authorities, manufacturers etc.)

The system to be tested in a small-scale field-test with instrumented vehicles is usually in its development phase, therefore the target group of the outcome are mainly researchers, system developers and manufacturers, and to some extent also public authorities, if they want to know in an early phase what could be the effects of a new IVS.

2.4 Resources needed

2.4.1 Organisational

Small organisational effort is needed to recruit the test persons and arrange the tests.

2.4.2 Personnel

Experts in behavioural sciences and statistics are needed in order to design the tests and to analyse the collected data. Mechanics and electronics engineers may be needed to install the systems.

2.4.3 Technical

One or a few instrumented vehicles are needed, including sensors and measuring instruments and the IVS of study. Also some additional tools

or software packages can be used to analyse the data (e.g. excel, SPSS, Matlab).

2.4.4 Financial

Most important costs are the cost for one or a few instrumented vehicles. Also, personnel costs for the researchers are needed and the participants are often paid a little amount.

3 Orientation of the method

3.1 Theoretical / empirical; Ex-ante / ex-post

The orientation is empirical, since real-world measurements are done, and ex-ante, since the system is usually not yet fully developed and not yet on the market.

3.2 Experimental / natural

The method can be both experimental and natural; experimental when specific situations are provoked to test the driver behaviour in certain situations, such as lane changes or approaches at intersections. Some extra vehicles could be used to create the right circumstances, e.g. approaching the intersection from another direction, or creating a small gap for a lane change.

When there are no specific situations provoked, the method is natural.

3.3 Background

The use of field studies relies on the idea that it is essential to get experience about the real use of the systems in real context, to study and to get new ideas for the ITS systems, in addition what was potentially found in a laboratory or simulator. A small scale field study is furthermore easier to perform in an earlier development phase than a large-scale field operational test, since it requires fewer resources (less number of vehicles and systems installed in the vehicles and less participants).

4 Focus

4.1 driver behaviour

The changes in driver behaviour are derived from the logged data. A data logger is installed in the instrumented vehicles to record the data, such as speed, acceleration, position on the road, gear and settings of the IVS (e.g. speed choice and following distance for an ACC system).

Depending on the type of system, different parameters can be used to determine the behaviour. For instance, the lateral position is essential in a Lane Departure Warning System, but it will not seem so interesting in a speed limiter (even if it can provide useful information or help to find out unexpected behavioural changes). Speed is an essential parameter to describe the changes in driver behaviour and should always be included in the evaluation. Depending on the system a workload test could be useful, too (e.g. with the 'peripheral detection task', where the participant has to react on a blinking light in his eye-corner.).

These objective data can be completed with subjective data, which can be collected through a questionnaire or an interview. The drivers can be asked about their opinion and feeling about the system characteristics, to assess the acceptability and usability of the system. Depending on the system and measurement equipments, a workload test could be included.

4.2 traffic flow and efficiency

The impact on traffic flow can be assessed via extrapolating the changes in the driver level to the whole traffic flow assuming different vehicle flow equipment levels. A traffic simulation model can be helpful for this. Also, conclusions on traffic flow and efficiency can be drawn from measured driving behaviour indicators such as headways and speeds (shorter headways will increase capacity).

4.3 Traffic safety

The impact on traffic safety can be assessed from measures like mean speed or headway distance, as there are studies which link the changes in these parameters with crash risk or injuries severity in case of accident. Traffic safety can also be measured with the help of serious traffic conflicts, also called near accidents. The direct measurement of safety in terms of accidents and their victims is not possible in small-scale field studies, since the probability in these is very low.

Concerning the safety criteria from chapter 2.1, they can be taken into account in a small-scale field study with instrumented vehicles as follows:

- Impacts on crash risk: higher mean speed indicates a higher crash risk. Also serious traffic conflicts can be studied, which can be evaluated with surrogate safety measures such as Time To Collision.
- Impacts on crash consequences: also related to mean speed and speed just before a collision or serious traffic conflict.
- Impacts on exposure: subjective data can be derived from questionnaires on mobility behaviour (route choice, number of trips).
- Impacts by road user: in a small field test with instrumented vehicles, only car drivers are taken into account, but there can be made a distinction in driver characteristics such as age, gender etc. Increasing the number of road user categories means increased sample size.
- Forecasting of traffic data: usually not done in a field study
- Forecasting of accident data: usually not done in a field study
- Impacts by road type: can be derived from the loggings of the instrumented vehicles, by using map-matching on the logged positions to find the corresponding road types.
- Impacts by vehicle type: is usually not assessed in a small-scale case study, since only one or a few vehicles are used and the number of vehicles per vehicle types is therefore not large enough for statistical significance.
- Impacts by weather conditions: can be determined by adding weather variables to the data loggings of the vehicles, e.g. from rain and temperature of weather stations nearby or by selecting the situations to perform the measurements based on the actual weather conditions.

- Impacts by lighting conditions: can be assessed by adding lighting conditions (e.g. sunset times or measured with on-board sensors) to the data loggings of the vehicles or selecting the situations beforehand with the desired lighting conditions.

4.4 Environment

The emissions of the cars can be derived from detailed measurements of speeds, accelerations and gear. Also, it can be measured directly from the exhaust with special sensors installed in the car, but this is expensive and deriving it from logged speeds etc. is generally accurate enough.

5 Description of the method

5.1 Short description of the underlying principles

The drivers are supposed to drive normally while they are participating in the study, so the data will show how drivers use the system and how their behaviour changes because of it.

The results validity will be better as the sample is well chosen and really represents the real population.

5.2 Type of assessment (desktop, lab, simulator, field, statistics)

Field study.

5.3 Process/design

5.3.1 Test persons

Typically, the sample size is quite small. With small sample size it may be better not to try covering the whole driver population, but selecting and defining driver groups based on only a few characteristics (e.g. only young or old drivers), in order to be able to derive the causes of the measured effects with higher certainty. Generally, the sample should be as similar as possible to the population which is intended to be evaluated.

5.3.2 Sample size

The more people participating, the more reliable and transferable the results tend to be. The sample must be big enough to get statistically significant results. Usually samples of over 20 people per group are used.

5.3.3 Set-up, design

First, the research questions should be designed.

The next step would be define the scenarios to be tested and which data is going to be measured and how. In a small-scale field test with instrumented vehicles, a logger system is installed in the car in order to get the data from it.

In a small-scale field test with instrumented vehicles, usually a fixed route is chosen which has the desired characteristics (depending on the research question), such as motorways or urban roads, intersections, traffic lights or not, busy traffic or not.

When there is only one instrumented vehicle available, each participant can use the same vehicle during separate trips.

5.3.4 Measuring or technical equipment

The required equipment is composed of the cars with the IVS and the measuring equipments. Depending on what is intended to be measured, this can be only a small computer installed in the car or several sensors both in and outside the car.

5.3.5 Data requirements

Required background data are the profile of each driver and car. Data to be logged need to have sufficient accuracy (e.g. speeds per second for emission calculations). Also positions (gps) need to be logged to derive road types (map-matching). Ideally, also traffic data from the surrounding traffic is gathered, e.g. from loop detectors in the road, but often this is not possible.

5.4 Expertise needed

Expertise on data processing, analysis and statistics is needed, as well as general expertise on traffic and driver behaviour. Also, some technical expertise is needed on the sensors and data loggers in the vehicle and the ITS system which is going to be studied.

6 Results

6.1 Type of output

The type of output is the analysis from the logged data on driver behaviour, safety and use of the ITS system (how the drivers use it, how often, in which situations,...).

6.2 Parameters / description

In theory almost every parameter in a car can be measured, from the speed to the seatbelt usage. Typically, the most interesting parameters are the speed and the ones related with the system usage, which will depend on the system nature and functionalities. Some parameters which can be used to determine driver behaviour can be:

- Speed: It is the most used parameter as it depends directly on driver's decisions. Drivers usually pay much attention to their speed and they can control it very easily, so this parameter is directly linked with driver's intentions. Moreover, is easy to measure. Mean speed and standard deviation of speeds are the most frequently used parameters.
- Headway: This is also a parameter which drivers focus on, so it is linked to their conscientious behaviour. It can be measured easily if the car has a radar installed (e.g. in cars with ACC). The proportion of short headways or the headway distribution as such are often used to describe changes in behaviour.

- Steering behaviour parameters: The parameters related to the steering behaviour are also closely related to the driver performance.
- Lane lateral position: Number of unintentional lane border crossings, and time to lane crossing are some parameters used in studies.
- Accelerations: The measured accelerations can provide information about how hard or smooth is the driving. The proportion and number of very strong accelerations are often used. The number of instances of very strong jerks (first derivative of acceleration) can be used as an indicator of serious conflicts.
- Fuel consumption: This is an example of a parameter which is usually not controlled by the driver, but can help to determine the driving dynamics (e.g. large accelerations increase fuel consumption).
- Traffic conflicts: The number of serious conflicts are regarded as being approximately proportional to the number of crashes of similar type. The ratio between crashes and serious crashes reported by the police varies by crash type. Usually these are recorded manually by observers in the car or by the road side, but increasingly jerks from data logger data (see accelerations) are being used.
- Eye movements: number and frequency of fixations.

Furthermore, if a questionnaire is used, there can be subjective data like how useful is the system for the drivers or how they think their behaviour is affected by it.

7 Restrictions of the method

7.1 Limitations

The main limitation is that a small number of cars and participants is used, which makes the results less reliable. Also, since the participants know their data is going to be recorded, they may not behave normally even if they are told to drive like they always do.

Furthermore, with the instrumented vehicles, only effects on the behaviour of that car can be logged, but no information on the total traffic flow, such as densities and intensities. By combining the data with loop detector data you can get information on traffic flow as background data or context into the study.

7.2 Scalability; extension to real world

It concerns real world data already, but the results can be affected by the “learning effect” and the behaviour of the test persons can be affected since they know they are participating in a test.

The results can be scaled to e.g. national level, by using the measured parameters such as average speed and following distance, but this is not very reliable since the sample is small and there could be regional differences.

7.3 Reliability and risks

The reliability of the measurements is high, but there are some problems with the reliability of the driver behaviour as mentioned before:

Since the participants know their data is going to be recorded, they may not behave normally even if they are told to drive like they always do.

The sample size is usually small.

There could also be a safety risk if the system is very new and not yet extensively tested in a laboratory setting, especially when the system settings are changed or when dangerous situations are provoked to test the system and driver behaviour in these situations.

8 Examples of use

- Van der Horst, A. R. A. & Bakker, P. (2006). Driver behaviour in transitions in car following situations on motorways (Rep. No. TNO report TNO-DV3 2006-M034). Soesterberg, Netherlands: TNO Defence, Security and Safety BU Human Factors.

Driver behaviour

4.5. Combined driving simulator and field test

1 Short description of the method

The objective of this method is to predict if and how the ITS system improves the road safety, using data obtained through driving simulator and on-road tests. These two types of test are complementary because usually the results obtained in the field test will be more accurate, but the driving simulator allows testing some situations which would be very dangerous on a real road. Also, the driving simulator tests can be used to let the drivers adapt to the system before driving with it in the real car.

2 Context of the evaluation

2.1 Phase – lifecycle of the product / Intelligent Vehicle system

The driving simulator study can be done in the first phases of the lifecycle (idea, plan, ...). But as the field test can only be done in the last phases, it would be preferred to use this method only in the large-scale demo or full-scale implementation phases.

Even if it is possible to do the on-road tests in a previous phase of the lifecycle, it is not recommended because of the high-cost of implementing the system in several real cars. Moreover, if the system is not completely defined yet, it might not be possible to extend the results to the final version of the system.

2.2 Expected outcome, research questions

The expected outcome is to get insight in the accident reduction due to the ITS system use, depending on the estimated penetration rate. Typically, this reduction will be calculated using the speed behaviour changes observed in both the simulator and on-road tests.

2.3 Target group of the outcome (public authorities, manufacturers etc.)

Mainly public authorities, as it provides the safety effects in terms of avoided accidents. This can give input to a cost-benefit study also. It will be also interesting for the manufacturers in order to know more about the performance of the system in real-life situations. Moreover, if several versions of the system are tested in the simulator or in the field test, the manufacturer can know which one is more attractive to the drivers.

2.4 Resources needed

2.4.1 Organisational

For the driving simulator it is needed to plan the experiment and prepare the simulator and software. For the field test, it is necessary to find participants who have a car with the system. If this is not possible, the system will have to be installed in the cars or some prototypes are needed to be lent to the participants. In this case, maybe special

permission from the authorities will be required, in order to have the modifications in the cars authorized.

A recruitment process has also to be realized for on-road and simulator tests. The participants can be different or the same for both tests.

2.4.2 Personnel

For the simulator study, at least one expert in driving simulation is needed in order to prepare the tests, scenarios and to handle the simulator. For the field tests, a mechanic may have to install the system in the cars. A person who explains the system and simulator usage is needed. Sometimes this person also accompanies the participant in the car during the simulator sessions and observes the behaviour.

Experts in statistics, data acquisition and processing are also needed in order to collect and analyse the data.

2.4.3 Technical

A driving simulator and its software are needed. It may be necessary to have some specific HMI for the system to be installed in the simulator cockpit. Maybe some prototypes can be also needed for the field test if it is not possible to find cars with the system installed. The proper sensors to measure and record the required data are necessary. Finally, some additional tools to analyse the data like SPSS.

2.4.4 Financial

These kinds of studies are expensive, as a driving simulator and field test costs are usually high. Maybe some cars will have to be modified or leased and the participants usually should be paid.

3 Orientation of the method

3.1 Theoretical / empirical; Ex-ante / ex-post

The orientation is empirical and ex-post.

3.2 Experimental / natural

Usually in a driving simulator the method is experimental as the main advantage in using a simulator is the possibility to control almost every variable in the environment. In a field test, the observation can be natural, but it is not common.

3.3 Background

Limited resources in research call for optimal use of evaluation methods. This method includes effective evaluation methods for different purposes. The idea in this method is to integrate two approaches: It is assumed that driver behaviour monitoring in a simulator provides tentative results about behavioural changes; the results are then verified with field measurements in real context. In the driving simulator, situations can be tested which do not occur often in reality or which are dangerous to test in reality. However, results of simulator studies may be questioned because the driver in a simulator is acting in an artificial situation, knowing that no real

crashes or danger can occur. The combination with a real-world field test improves the ecological validity of the results considerably. In addition, it provides more general knowledge about the relationship between behaviour in a simulator and behaviour in real traffic.

The accident reduction is estimated based on relations between speeding and crash risk demonstrated in previous studies.

4 Focus

4.1 driver behaviour

The driver behaviour is derived from the measurements taken (typically from the mean speed). This data can be completed with a questionnaire. It is very difficult to find changes in the strategic level, but there can be a lot of information about changes at the tactical level (e.g. speed or headway).

4.2 traffic flow and efficiency

The impact on traffic flow can be inferred via crudely extrapolating the changes in the driver level to the whole traffic flow assuming different vehicle flow equipment levels.

4.3 Traffic safety

The impact on traffic safety is inferred from the speed behaviour observed in the tests (simulator and on-road), using the results of previous studies which link the parameters like mean speed to crash risk and severity.

Moreover, in the driving simulator tests an estimated reduction of a specific type of accident can be done. For instance, testing the effects of ESC on a wet road (specific situation). If an objective reduction in the crashes can be observed between the control group (without the system) and the system group, then it can be concluded that the system implies an accident reduction for this situation and it will be also possible to estimate the general magnitude of the effect on the basis of behavioural changes.

If the system is voluntary, it is also interesting to find which percentage of the people with the system installed will use it, so the accident reduction can be pondered by this parameter.

Concerning the safety criteria as presented in chapter 2.1, the following impacts can be assessed with a combined driving simulator and field test, as found in (1):

Impacts on crash risk and crash consequences: derived from changes in speed.

Impacts by road user: can be assessed by using different user profiles in the study, such as gender, age, motorist or car driver etc.

Forecasting of accident and traffic data: can be done by estimation of the future system penetration rate, and estimation of the dependencies with system penetration rate on traffic flow and accidents.

Impacts by road type: in (1), the impact on road type is differentiated for rural road, motorway and urban areas, as well as between peak and off-peak time.

Impacts by vehicle type: could be investigated in a field test, but was not relevant in (1).

Impacts by weather and lightning conditions: could be investigated in a driving simulator or field test, but was not covered by (1).

4.4 Environment

The emissions of the cars can be derived from detailed measurements of speeds, accelerations and gear. Also, it can be measured directly from the exhaust with special sensors installed in the car, but this is expensive and deriving it from logged speeds etc. is generally accurate enough.

It can also be measured in the driving simulator using an emission modelling software.

4.5 Socio-economic

The accident reduction estimation can be used to calculate a cost-benefit ratio.

5 Description of the method

5.1 Short description of the underlying principles

The participants just have to drive normally during the experiments. Usually a baseline is needed, at least in the driving simulator, as the measures taken in a simulator can't be extended to the real world directly. But with a baseline, behavioural comparison can be done and extended to an on-road situation.

Once the data has been collected and analysed, it is used to make an accident reduction estimation, based on the results of previous crash studies which link the accident risk to a measured parameter (typically speed). If a change in the parameter is observed, it is supposed to provoke also a change in the accident risk. This relation is usually not direct, and crashes usually have many contributory factors so the estimation must be made by crash experts who are able to know how the change in the parameter can affect the crash rate.

5.2 Type of assessment (desktop, lab, simulator, field, statistics)

Field (simulator and on-road tests) and desktop (accident estimation).

5.3 Process/design

5.3.1 Test persons

The sample should be as similar as possible to the population which is intended to be evaluated. With small sample sizes a homogenous group is preferred in order to be able to derive the cause of the changes with more certainty, with a larger amount of test persons a heterogeneous sample can be considered (i.e. wide age range, different driving times, etc.) to reflect the real population better. The same sample for both tests (simulator and field) can be used.

5.3.2 Sample size

The more people participate, the more accurate the results will be. It depends also on other design factors as how many groups it would be. For instance there can be a control group (i.e. without any system) and some groups with different systems or different versions of the system. There can be also several groups for each type of car. The sample must be big enough to get statistically significant results. Usually samples over 20 people per group are used.

5.3.3 Set-up, design

First, for the driving simulator, it is necessary to decide which are going to be the test situations and scenarios. The driving simulator test can have two aims: first, it can be used to test dangerous or unlikely situations which will be impossible to do in a real car. The other possible purpose is to make the system familiar to the participants, so they will learn how it works and will adapt to it before the field test. Doing this, the “learning effect” is reduced, so the data collected in the road tests will be more accurate, and it will also improve the participants’ safety in the field test, avoiding dangerous situations caused by wrong system usage. Of course, this second aim is only valid if the participants in the simulator and field tests are the same.

In the field test, the participants should be divided in several groups. First, a control group is needed as baseline. Other groups can be formed in order to test different system versions or HMI concepts.

An acceptance and usability questionnaire after the tests (both simulator and on-road) is recommended to receive information which can e.g. be used to estimate the penetration rates that can be reached. After performing the tests, the collected data must be processed and analysed. This data will be used to make the accident estimation. To do the estimation, the field test data is more suitable, as it comes from a real car, but the registered data from the simulator can also be taken into account.

Finally, it is necessary to find the theoretical background about how the speed behaviour is related to the accident risk, in order to estimate the crash reduction. This information is usually found in previous in-depth crash studies. In this case, it is important to use studies of the same region in which the field test was done.

5.3.4 Measuring or technical equipment

The technical equipment needed is composed by a driving simulator, the test cars (owned by the participants or not) and the measuring instruments (sensors and data logger for cars and simulator).

5.3.5 Data requirements

Data from previous crash studies is needed in order to estimate how many accidents would be affected due to the behavioural changes related to the system usage.

The profile of each driver and car could also be interesting.

5.4 Expertise needed

Expertise in driving simulation, experimental design, statistics, data processing and analysis is needed. Expertise in in-depth crash data studies is also desirable in order to make the accident reduction estimates.

6 Results

6.1 Type of output

The main output is the estimated accident reduction. Other parameters which can be used to calculate this reduction, can also be given as output (speed choice, acceptability and usage of the system, estimated penetration rates,...). Moreover, the data obtained in the driving simulator and field tests can be used to calculate the effects of the system in other fields like consumption or emissions.

Finally, the estimated crash reduction can be used to give a benefit-cost ratio.

6.2 Parameters / description

In theory almost every parameter in the cars can be measured. Typically, the most important parameters used today to estimate changes in safety are speed and TTC (time to collision). Traffic conflicts via manual observation or data logger data analysis can also be used. Moreover, it is interesting to have a questionnaire to find out if the participants would be interested in installing the system in their cars, so a penetration rate can be predicted. If the system is voluntary, the field tests can show which percentage of the users will activate it and how often. This information is very useful because the accident reduction can be lower than estimated if the drivers don't use the system very often.

7 Restrictions of the method

7.1 Limitations

The main limitation is that it is needed to have a high number of cars with the system installed in order to get representative and statistically conclusive results.

Moreover, if the participants will know they are participating in a study, they may not behave normally.

On the other hand, the final output is an estimation based on the study data, which can be quite restricted. With regard to safety, it is also based on previous crash studies and accident statistics, so the method is limited by the existence of such data. With regard to efficiency and environment, flow and fuel consumption data and statistics are required.

7.2 Scalability; extension to real world

It is real world already, but as the field tests are done with a very small penetration rate (usually the rest of the road users won't have the system), in certain systems this will imply a slightly different driver behaviour compared with a situation where the system is popular and has been installed in a high percentage of the cars. As the estimation is made in long-term, this difference can make the results less accurate. The

outcome is always an estimation, so it must be used or extended with prudence.

Finally, if the system is very new, the results can be affected by the “learning effect”.

7.3 Reliability and risks

The reliability depends on how big the sample was and how long the participants have driven with the system. The accident reduction estimation can be very reliable if the theoretical background is well stated and correctly applied.

8 Examples of use

1. Carsten O., Fowkes M. (2000). External Vehicle Speed Control. <http://www.its.leeds.ac.uk/projects/evsc/exec3.pdf>

This study goes further and not only makes an accident reduction prediction, but also takes into account effects concerning environment and socio-economic issues.

Mobility

4.6. Travel diaries

1 Title and short description of the method

Travel diaries

Travel pattern study (one day travel diaries) based on questionnaires.

2 Context of the evaluation

2.1 Phase – lifecycle of the product / Intelligent Vehicle system

Travel diaries are used to report real travel patterns. The phase of the product should therefore be already on or almost ready for the market. It can be used in pilots, FOTs or large-scale demos.

2.2 Expected outcome, research questions

The reference study [ref] utilised the results in recommending decisions and providing information for a referendum about the deployment of road user charging.

2.3 Target group of the outcome

This method is often used as a data collection tool for transport system planning. It is therefore very useful for public authorities.

2.4 Resources needed

2.4.1 Organisational

Small organisational effort: composing instructions and questions for the travel diaries, selecting a group of participants, instruct and guide the participants, receive the travel diaries and analyze them.

2.4.2 Personnel

Transport Engineering and Planning

The efficiency relies on the application of the method, but basically the method can be applied quite efficiently with automated scanning of responses. Nevertheless a large amount of manual work needs to be done especially for the unstructured answers with written comments. A person with transport background is useful to interpret the results.

2.4.3 Technical

No special technical requirements Travel diaries can be postal or web-based questionnaires. In the latter case, the questionnaires should be implemented in a web-based environment, which requires a normal pc or possibly some additional software.

2.4.4 Financial

Low financial expenses, no hardware costs, low personnel costs

3 Orientation of the method

3.1 Theoretical / empirical; Ex-ante / ex-post

Empirical before and after study

3.2 Experimental / natural

This method analyzes the natural mobility and travel behaviour.

3.3 Background: theoretical, practical

It is a practical method, in the sense that real-world behaviour is reported. The analysis requires a theoretical (statistical) background.

4 Focus

4.1 Mobility

The method is capable of determining the average mobility behaviour or the mobility behaviour of a group of people with certain characteristics, before and after the introduction of the IVSS. Mobility issues that can be covered by travel diaries are e.g. impacts on number of journeys, length of journeys, travel mode, destinations, routes, timing of trip, journey quality (stress, subjective safety, comfort). Also the differences for different trip purposes (e.g. commuting, leisure, business) can be analyzed.

5 Description of the method

5.1 Short description of the underlying principles

Travel diaries are considered widely to capture the daily journeys in an appropriate manner. The travel diary is a survey instrument designed to record all movements during the course of one or more days including their relevant details. It can be complemented by separate household and personal forms for recording general information.

5.2 Type of assessment (desktop, lab, simulator, field, statistics)

The travel diaries are assessed with a desktop study and statistical analysis.

5.3 Process/design

5.3.1 Test persons

A desired distribution over relevant aspects of the participants should be chosen, such as gender, age, possession of driver license, income etc.

Usually this distribution should be equal to the distribution of the total population.

5.3.2 Sample size

The group of test persons should be large enough for statistical significance (as a rule of thumb, minimal around 30).

5.3.3 Set-up, design

Before and after study (before and after the introduction of a certain IVSS) with large panels of persons.

Compose instructions and questions for the travel diaries, select a group of participants, instruct and guide the participants, receive the travel diaries and analyze them. The same persons in before and after phase should be matched. The non-respondents could be included with a separate enquiry.

5.3.4 Measuring equipment

No special measuring equipment needed, it concerns self-reported behaviour of the participants.

5.3.5 Data requirements

No input data are required for a travel diary study, except information to compose relevant questions for the travel diaries. The number of questions is to be minimised in order to get a better response rate.

5.4 Expertise needed

Expertise is needed on composing questionnaires for the travel diaries, setting-up the travel diary study (selecting test persons, communication and instruction to the test persons, collecting results) and the statistical analysis of the results.

6 Results:

6.1 Type of output

The output is a statistical report of the travel diaries, which usually includes impacts on travel modes, destinations and timing of trip.

6.2 Parameters / description

Examples of output parameters are:

- Number of journeys by mode
- Length of journeys
- Journey quality: stress, subjective safety, comfort
- Separate results for different trip purposes, such as commuting trips and leisure time trips.

Long term effects can be studied by performing an after measurement long after the introduction of the IVSS.

Furthermore, the mobility output can be complemented by separate household and personal forms for recording general information, such as employment, consumption level and area of living.

7 Restrictions of the method

7.1 Limitations

The travel diaries should be kept short in order to get a better response rate. Therefore, not all relevant aspects, such as rationale for mode choice in individual journeys, are covered in detail. Also, since it concerns self-reported behaviour, there is no guarantee on the correctness and completeness of their responses.

7.2 Scalability; extension to real world

The method is applied in a real world situation, in an existing transport system. Scaling the results of the study to e.g. city or regional level with the same transport system is straightforward. Scalability to other cities or regions with a different transport system is not always possible. However, general results about e.g. number and lengths of journeys are usually applicable on a much larger scale (e.g. the "BREVER-law" states that on

average, everyone spends the same amount of time to travelling, no matter when or where).

7.3 Reliability and risks

The quality of the travel diary study depends on the selection of respondents with regard to the sample size, the coverage of journeys and other relevant factors, the willingness to respond by the participants and the accuracy of their responses. If the sample size of the participants is large enough, satisfactory accuracy (with statistical significance) can be obtained.

8 Examples of use:

- Andreas Allström, A.; Lovisa Bengtsson, L.; Karin Neergaard, K.; Annika Nilsson, A.; Lena Smidfelt Rosqvist, L.; Liselott Ström, L. & Linnea Viklund, L. (2006). Changes in travel habits in Stockholm County – Effects of the Stockholm Trial. Trivector Traffic, Report 2006:67.
<http://www.stockholmsforsoket.se/upload/Sammanfattningar/English/Changes%20in%20travel%20habits%20in%20Stockholm%20County.pdf>

Efficiency and traffic flow

4.7. Traffic simulation

1 Short description of the method

Traffic simulation is a means to represent a traffic situation by a mathematical model (with computer software). This traffic situation holds a traffic network of one or many roads of a road network and up to thousands of vehicles. By simulating a change in the traffic situation, such as the introduction of an IVS, the effects on the traffic flow in a network can be studied.

2 Context of the evaluation

2.1 Phase – lifecycle of the product / Intelligent Vehicle system

Traffic simulation is especially suitable when the ITS system or traffic situation does not yet exist in the real world. It is therefore especially suitable for the idea and plan phases. Also suitable for ex-ante tests, e.g. to use before a large field operational test will be set-up, to get an idea about the requirements for the field operational test, such as the required penetration rates, system design and settings etc. Furthermore, it can complement a pilot or large-scale demo. In a pilot or demo, usually only a few vehicles are equipped. Traffic simulation can be used to evaluate the effect for larger penetration rates, or for other traffic demands than were encountered during the pilot.

The method can also motivate the decisions to either continue or stop a system or service development based on the effects the systems seems to have on network level

2.2 Expected outcome, research questions

The expected outcome are the effects of a (new) ITS system on a network level in terms of speeds, traffic counts or other traffic parameters. These can be used to derive effects on both traffic flow/efficiency, safety and environment. Research questions can for example be: "Will the air quality at this location improve as a certain IVS is applied?" or "How many accidents could be avoided by applying this type of IVS at 1% of all vehicles?", or "What will be the effect of this IVS on the average travel time between A and B?"

In the case of macrosimulation, large network effects can be determined on an aggregated traffic level (average speeds and flows per link) of up to a whole country (or more, depending on the available computational power and detail of the network). With microsimulation, the traffic is simulated at the individual vehicle level, which gives the opportunity to define and evaluate the ITS system on an individual vehicle level, however, the size of the network that can be simulated is smaller due to the higher complexity and required computational power.

2.3 Target group of the outcome (public authorities, manufacturers etc.)

Mainly public authorities, such as cities, regions or national road authorities. The method focuses on traffic flow effects on a larger scale (in

a network, effect of many equipped vehicles), which is of interest of public authorities, but of less interest for individual users, manufacturers etc. It can show the possible benefits of IVSS on traffic flow in road networks. Results can be important for decisions makers such as road authorities / operators / managers e.g. to support further research on IVSS. However, it could also be used to design the system in such a way that the desired effects will be reached (e.g. higher traffic flow efficiency (increased road capacity), better safety by better stability of the traffic flow). System settings and algorithms can be tested beforehand. It can therefore be useful for manufacturers too.

2.4 Resources needed

2.4.1 Organisational

Traffic simulation does not require special organisational resources, as long as the personnel and technical resources are covered, such as a licence for a (commercial) traffic simulation model.

2.4.2 Personnel

Fairly high expertise and experience in traffic simulations is needed, such as expertise on calibration of traffic models, traffic flow theory, driver behaviour modelling and programming (depending on the used simulation model and the type of changes that need to be modelled, some changes are possible without programming, other changes can require programming in Java, C etc.). Interpreting (random) values of simulation runs requires furthermore statistical expertise.

2.4.3 Technical

A traffic simulation model is needed (e.g. Vissim, Paramics, Aimsun), as well as computers with sufficient computational power. Normally, a modern pc is sufficient. Also some additional tools or software packages may be used to analyse the data (e.g. excel, SPSS, Matlab).

2.4.4 Financial

A traffic simulation study requires relatively modest investments. The only required finances are for the licence costs for the traffic simulation model (sometimes up to 10000 euro's), computer hardware (normal pc) and for the required manpower and time (some weeks to some months).

3 Orientation of the method

3.1 Theoretical / empirical; Ex-ante / ex-post

The orientation is mainly theoretical and ex-ante, however, empirical data can be used to calibrate the model in order to resemble a real-life situation.

3.2 Experimental / natural

The method is experimental, in the sense that it is no real-world situation, but a simulation (matching as good as possible with the real-world).

3.3 Background: theoretical, practical

The method is theoretical, since the simulation with the ITS system does not exist (in the exact form as simulated) in the real-world (otherwise it would have no use of simulating it).

4 Focus

4.1 driver behaviour

The driver behaviour can be changed (due to the IVS) at the strategic and tactical level.

At the strategic level, route choice can be changed (e.g. if certain routes become less congested). Most traffic models already use algorithms to determine the route choice based on the travel times between origin-destination pairs, e.g. by determining the equilibrium assignment in which none of the drivers can improve their travel time. If the route choice will change differently due to some IVS, e.g. due to better availability of traffic information for some of the drivers, the traffic model has to be extended in order to be able to model this. Some traffic models contain a module to simulate this kind of route choice behaviour (e.g. the ITS modeller).

Driver behaviour can also change at the tactical level due to an IVS (e.g. speed choice). This also has to be modelled in the traffic simulation model. Some traffic simulation models only allow certain parameters to be changed. In order to be able to model the effects of every possible IVS, a simulation model with an open Application Programming Interface should be used (e.g. Paramics, Vissim).

4.2 traffic flow and efficiency

The focus of traffic simulation studies is usually traffic flow and efficiency. To study this, indicators like average speeds, flows and travel times are derived from the simulations. See also 6.2 with examples of traffic flow indicators.

4.3 Traffic safety

Traffic safety issues can also be studied from traffic simulation results, however, this is tricky since accidents are statistically insignificant in numbers during short time periods, such that you cannot generate them in a realistic short-time simulation. Also, the driving behaviour in simulation models is usually programmed such that driving errors which can cause accidents can not occur. Therefore, if safety studies are done based on micro-simulation studies, usually this is done by analyzing so called "surrogate safety measures", which represent dangerous situations with a higher accident probability. Examples are critical "Time-To-Collision" (the time until two successive vehicles would collide if their speed and trajectory remained unchanged), short headways, speed difference between successive vehicles and between adjacent lanes, proportion of small headways, frequency of strong decelerations etc. Usually these indicators can be used to derive relative conclusions such as "in the new situation, the accident probability will reduce", but not in terms of absolute number of accidents. However, there are some research attempts which try to develop accurate driver models and calibrate this with extensive

traffic and accident data in order to be able to derive such conclusions in terms of numbers of accidents, but these models are not yet available in commercial traffic simulation software.

On a more aggregate level, indicators such as change in average speeds, flows and total vehicle kilometres can be used to derive conclusions about the safety, e.g. by using average numbers of accidents per vehicle kilometre per road type.

More specifically, the defined safety criteria from chapter 2.1 can be met as follows:

- Impacts on crash risk: derived from surrogate safety measures as described above.
- Impacts on crash consequences: derived from surrogate safety measures that are indicators the accident severity, such as speed difference of the two vehicles just before colliding.
- Impacts on exposure: can be derived from flows. Also, route choice has an influence on exposure, so the microscopic model should have a well calibrated route choice model.
- Impacts by road user: Usually, only car drivers are taken into account, but some microscopic models model cyclists and pedestrians as well.
- Forecasting of traffic data: forecasting future traffic demand, e.g. with extrapolation or scenarios based on (economical) predictions from other studies, and Origin-Destination matrix prediction (different models and algorithms exist for this).
- Forecasting of accident data: can be done by using the forecasted future traffic demand.
- Impacts by road type: the effects can be analysed per road type present in the simulations.
- Impacts by vehicle type: the effects can be analysed per vehicle type present in the simulations, however, this only makes sense if the microscopic model properly models the differences between the different vehicle models.
- Impacts by weather conditions: can be taken into account by changing the driver behaviour models for other weather conditions, such as longer following distances in heavy rain.
- Impacts by lighting conditions: can be taken into account by changing the driver behaviour models for other lighting conditions, such as longer following distances in the dark.

4.4 Environment

The output of traffic simulation models can be used to derive emission effects of e.g. CO₂, NO_x, PM₁₀ with the help of emission models. This can be done again at an aggregate or more detailed level. At the aggregated level, emissions are calculated from average speeds and flows and average emission factors. However, since emissions depend strongly on the dynamics (accelerations) and the composition (percentage heavy trucks, diesel vehicles) of the traffic flow, and IVS systems usually intervene on the level of individual speeds and acceleration behaviour, a detailed approach with microsimulation is recommended. Since traffic

microsimulation models simulate individual driver behaviour, such as speeds and accelerations per second (or 0.1 second), detailed emission calculations are possible. There are some (commercial) emission models available that are able to calculate emissions based on these microscopic vehicle trajectories (e.g. the TNO emission model Enviver in combination with Vissim). The accuracy of these calculations are much better than calculations based only on average speeds and flows, however, it depends on the accuracy and calibration of the acceleration behaviour of the microsimulation model¹.

5 Description of the method

5.1 Short description of the underlying principles

With a microscopic traffic simulation model, vehicles are simulated at an individual vehicle level in a simulated network, usually of the size of a small network and thousands of vehicles, e.g. part of a town. Both traffic management and in-car systems can be modelled.

In the simulation model, vehicle and driver behaviour is modelled on the individual vehicle level, with mathematical rules that define the driver behaviour in relation to the surrounding vehicles in terms of speed, headway etc. These rules contain (among others) the car-following behaviour, free flow behaviour and lane change behaviour.

5.2 Type of assessment (desktop, lab, simulator, field, statistics)

A traffic simulation study is a desktop study, which can be performed on a normal pc. However, some real-world measurement data is often used to calibrate the model.

5.3 Process/design

5.3.1 Test persons

The method does not require test persons.

5.3.2 Sample size

To represent the stochastic nature of traffic, microsimulation models use random variables. In order to be able to draw statistically significant conclusions, therefore several simulation runs of the same scenario are usually done, usually 5 or 10 (depends on the variability of the output values). The resulting values are averaged from the separate simulation runs.

5.3.3 Set-up, design

First the network in the microscopic traffic simulation model is constructed and calibrated, if possible with real-world traffic data. This includes the calibration of OD-matrices and traffic counts at certain locations in the network.

Next, in order to study the effects of ITS, the changes in driver behaviour on the level of the behavioural rules and input parameters should be determined and implemented.

¹ A recent study revealed that the default acceleration behaviour in some microsimulation models should be adapted in order to get realistic emission calculations ([ref T3]).

The scenario's that will be evaluated have to be determined and implemented (e.g. different penetration rates of the ITS system).

Also the output parameters to be analysed have to be determined, and the simulation model needs to be initialized such that the desired output parameters will be logged during the simulations.

In order to get statistical significant results, a number of simulation runs with different random seeds will be done per scenario.

Finally the results will be analyzed in order to study the effects of the ITS system.

5.3.4 Measuring or technical equipment

The required equipment is a (microscopic) traffic simulation model (e.g. Vissim, Paramics, Aimsun) and a (normal) pc suitable for the microsimulation software. The microsimulation model should have an open interface to adapt the driver behaviour or add traffic management and IVS.

5.3.5 Data requirements

Required data are the road lay-out and infrastructural features of the road network (coordinates of roads and crossings, curvatures, number of lanes etc), as well as traffic data of the studies network. These are e.g. traffic counts (per vehicle type) and speeds at several locations in the network, or, if possible, number of trips per origin-destination pair per time of day.

Furthermore, to adapt the driver behaviour, information is needed on how the driver behaviour will change. (This could e.g. be tested in a driving simulator).

5.4 Expertise needed

The required expertise is expertise on using microsimulation models, using and calibrating the model, programming for adapting the driver behaviour of the model (usually by an API in C or Java), knowledge of traffic flow indicators and traffic analysis.

6 Results

6.1 Type of output

The output is (quantitative) traffic data and derived indicators from the simulation runs. Also more advanced analysis can be done with additional methods or statistical analysis and reported in graphics, numbers and text.

6.2 Parameters / description

In principle, every indicator at the individual vehicle or network level can be derived. This can include e.g. vehicle trajectories for environmental effects, safety indicators such as Time To Collision and traffic flow efficiency parameters such as average speeds, total vehicle delay hours etc.

Some examples of traffic flow indicators which are often derived from and analysed in traffic simulation studies are:

- Impacts on speeds
- Impacts on flows

- Impacts on density
- Impacts on headways.
- network total journey time
- network total delay time (difference of free flow travel time and realized travel time)
- travel times
- Impacts on congestions
- homogenisation of traffic flow (e.g. decreasing standard deviation of speeds).
- Impacts on safety by means of surrogate safety measures (TTC, proportion of small headways, speed differences etc.)

From these traffic data, by post processing with extended models also indicators related to environment can be derived (e.g. fuel consumption, emissions for pollutants CO, NO_x, and HC)

7 Restrictions of the method

7.1 Limitations

The main limitation is that it is a simulation, hence you will never be 100% sure that the result will be the same in the real-world. However, a good calibration procedure based on real-data can reasonably guarantee a representative traffic situation, though calibrating the network is demanding in terms of both real-world data and expertise.

Concerning the driver behaviour, both the reference behaviour (non-users) as the behaviour of the drivers equipped with the IVS need to be modelled in a reasonably correct and realistic way, including differences between drivers. In principle this is possible, e.g. by using detailed traffic data or driver simulation studies. In practice, good detailed data (on individual driver level) is often lacking, in which case assumptions are made or results from earlier studies are used.

Also, most (microscopic) traffic models are not multi-model (do not include public transport).

7.2 Scalability; extension to real world

Traffic simulation models are usually used to represent a real-world traffic situation, based on real world traffic data and road lay-out.

Transferring or generalizing the simulation results to other traffic situations is possible if the simulations are set-up with scenarios that cover different traffic situations (e.g. different traffic demands, penetration rates, road types). This can also be used for forecasting effects for future penetration rates, vehicle fleets and traffic demands.

Upscaling the results to the country or even EU-25 level is not common, but theoretically possible, however, the problem for this is the (lack of) data availability on country and EU level. Data which are needed are e.g. vehicle kilometres per road type, and differences in vehicle fleets and driver behaviour between countries.

7.3 Reliability and risks

Since it is a simulation, a 100% reliability of the results cannot be guaranteed. However, it is possible to derive confidence limits or similar

error margins for the impact estimates, based on several runs. Since (microscopic) traffic simulations are based on stochastic processes, different runs produce different results, just like in reality the same traffic situation in terms of hourly demand could lead to different realizations concerning congestion, accidents etc. By increasing the number of runs, the likelihood of various outcomes can be more accurately estimated.

The reliability will depend on both the quality of the traffic data used for calibration and the driver models in the simulation model. Many research is going on on both topics².

Nevertheless, one could say that concerning traffic situations and systems that do not yet exist in the real-world, traffic simulation is a good means to get an idea of the effects, and about the best one could get for a non-existing situation.

8 Examples of use

- Network effects of Intelligent Speed Adaptation Systems

<http://eprints.whiterose.ac.uk/2489/>

This paper describes the developments made to enhance a traffic microsimulation model (DRACULA) in order to represent ISA implemented across a network and their impact on the networks. The simulation modelling of the control system is carried out on a real-world urban network (Sweden, the Netherlands, Spain and the UK), and the impacts on traffic congestion, speed distribution and the environment assessed.

- eIMPACT, "Socio-economic Impact Assessment of stand-alone and co-operative intelligent vehicle safety systems (IVSS) in Europe", Deliverable 4, 5.

eIMPACT was an European Specific Targeted Project co-funded by the European Commission Information Society Technologies and Media. This project focused on the socio-economic Impact Assessment of stand-alone and co-operative intelligent vehicle safety systems (IVSS) in Europe.

<http://www.eimpact.info/results.html>

Additional references:

S. Ossen. "Longitudinal Driving Behavior: Theory and Empirics", Ph.D. thesis TU Delft, 2008

² e.g. in (Ossen, 2008) calibration of driver models is done with the help of Helicopter data. This revealed that to represent the traffic behaviour best, a mix of different driver models for different drivers is needed.

Traffic safety

4.8. Expert assessment on safety impacts

1 Short description of the method

ITS systems affect driver behaviour in many, sometimes unforeseen and indirect, ways. Therefore, the systems usually also affect other accidents than those that the system was designed for to prevent or mitigate. It is needed to cover systematically all safety effects of each system describing the systems effects on behaviour and then transforming these into safety effects. The main objective of the method is to provide an independent assessment of direct and indirect impacts, costs and benefits of a set of chosen functionalities related to safety properties.

As the systems are new and their specifications have not been determined to any level of detail, a number of expert opinions on system functionalities, technologies, HMI, costs, vehicle market penetration, infrastructure coverage, and effects on driver and travel behaviour are needed.

2 Context of the evaluation

2.1 Phase – lifecycle of the product / Intelligent Vehicle system

The method is suitable already for the idea and plan phases. However, use of the method requires unambiguous system and functions specifications. The results provide a good basis to develop FOTs and to be validated in FOTs.

2.2 Expected outcome, research questions

The behaviour and safety effects differ according to various factors in order to estimate the effects on safety in terms of accidents and injuries, these factors need to correspond to those available in accident data.

Expected outcomes and research questions are:

- The impact estimates of ITS in terms of percent changes, numbers of fatalities and injuries
 - The user reaction to the system
 - How can user reactions and modification of the situation be 'translated' into expected safety effects?
 - How do these reactions depend on the characteristics of the system?
- How do the impacts depend on penetration degree?
- What other effects can be identified?

This method addresses how the system is planned to prevent or mitigate accidents, how the system changes the driver behaviour, handling the traffic situations and the vehicle compared with the situation without the system, how the system interacts with the driver, how the system

interacts with other applications, which requirements the system sets to the driver or the vehicle or infrastructure or scenario and how the system interacts with other applications.

2.3 Target group of the outcome (public authorities, manufacturers etc.)

Results are important for system manufacturers and designers and concept car makers. It should be used to design the system preserving safety requirements and features. The results provide a good basis for public authorities but a continuous analysis is needed to update the long-term predictions with the new data available.

2.4 Resources needed

2.4.1 Organisational

Preferably, different kinds of organisations are involved. Impartial research organisations are in central position to provide the knowledge and expert opinions. However, the OEMs are needed to provide the information on system specification. Especially, concerning cooperative systems participation of road authorities would be advantageous.

2.4.2 Personnel

High experience in traffic safety, driver behaviour and statistics is needed. Experts are needed in the following areas: psychology, statistics, technology, simulation. In addition, knowledge on the IVS system properties is needed.

2.4.3 Technical

No specific technical requirements are set.

2.4.4 Financial

The costs depend mainly on the person months required.

3 Orientation of the method

3.1 Theoretical / empirical; Ex-ante / ex-post

The orientation is mainly ex-ante, however, empirical data is used to analyse the safety impacts.

3.2 Experimental / natural

This aspect is not valid for the method.

3.3 Background

The method is partly theoretical and partly practical; The basis is theoretical but it is connected to empirical data from the real world. In many cases, experience on the systems in question does not yet exist, but with an expert assessment, assumptions can be based on earlier results concerning systems with similar properties and features, or on general knowledge about driver behaviour and expert judgments.

4 Focus

4.1 driver behaviour

The traffic demand used in the different scenarios was based on the level of service indicators. The study required the systems to be evaluated in situations where they are likely to be employed. Hence, the situations with accidents, congestions and weather were modelled. The reactions of drivers used as input to the modelling were determined by expert assessment taking into account literature on the different systems and their likely effects on driver behaviour. The whole method is based on linking the driver behaviour impacts to safety impacts.

4.2 traffic flow and efficiency

Changes in accident occurrence have also large effects in accident related congestion, and these are considered in the various impact mechanisms utilised in the method.

4.3 Traffic safety

The whole method is focussed on road safety, and aims to cover all possible effects of an ITS system on safety. The method fulfils all the assessment criteria for safety as presented in chapter 2.1. For the eImpact study (2), the criteria were assessed as follows:

Impacts on crash risk and crash consequences: estimated by expert assessment on modification of accident consequences (mechanism 9 in the eImpact study, below 'Parameters/Description').

Impacts on exposure: was taken into account by estimating the modification of road user exposure (mechanism 6), modification of modal choice (mechanism 7) and modification of route choice (mechanism 8).

Impacts by road user: estimated by expert assessment on direct in-car modification of the driving task (mechanism 1 in the eImpact study), indirect modification of user behaviour (mechanism 3) and modification of interaction between users and non-users (mechanism 5).

Forecasting of accident and traffic data: estimation of future penetration rates until 2025-2030.

Impacts by road type: Modification of route choice is estimated (mechanism 8). Also, traffic simulations are done for different road types.

Impacts by vehicle type: was not estimated.

Impacts by weather and lightning conditions: lightning conditions were taken into account a little, by estimating the accident distribution to time of the day.

4.4 Environment

Not relevant for the method

5 Description of the method

5.1 Short description of the underlying principles

The starting point for the safety impact assessment is the system specifications, including anticipated driver reactions. Next step is the relevant safety mechanisms were selected for each system studied, and the expected changes in driver behaviour were described. Each system was compared to the base or reference case with no system. Based on existing knowledge, a numerical percentage value for the change in fatalities and injuries was estimated for each safety mechanism.

5.2 Type of assessment (desktop, lab, simulator, field, statistics)

The assessment is a desktop study.

5.3 Process/design

5.3.1 Test persons

The method does not require test persons.

5.3.2 Sample size

This method does not require any sample size, only statistics of past accidents.

5.3.3 Set-up, design

Start with a clear system specification, including anticipated driver reactions. For each system and for each functionality the safety mechanisms are needed and the expected changes in driver behaviour are to be described. Each system will be compared to the base or reference case with no system. Based on existing knowledge, a numerical percentage value for the change in fatalities and injuries is estimated for each safety mechanism.

5.3.4 Measuring or technical equipment

Statistical techniques are applied.

5.3.5 Data requirements

The data requirements for applying the method are the exposure data in terms of vehicle kilometres driven, as well as the accident data disaggregated on the basis of the key factors identified in the method.

The factors were accident type, vehicle type, road type, weather, lighting, section (junction or not).

5.4 Expertise needed

The required expertise is focused on knowledge of safety impacts, psychology and statistics. Experience with the use of Excel is useful.

6 Results

6.1 Type of output

The impact estimates of ITS in terms of percent changes, numbers of fatalities and injuries in the selected target years. These are also disaggregated by accident type, road type, vehicle type, weather, lighting and section type (junction or not). This data is given in a form directly suited for input to Cost Benefit Analysis. In addition, the impact mechanism descriptions describe the effects of the systems on driver behaviour.

6.2 Parameters / description

When one element of the system is affected, the consequences may appear in several elements and levels of the system, both immediately and in the long term, due to behavioural modification. Road safety is regarded as a multiplication of three orthogonal factors: (1) exposure, (2) risk of a collision to take place during a trip and (3) risk of a collision to result in injuries or death.

The analysis covers the three main factors of traffic safety by nine behavioural mechanisms via IVSS affects safety.

The first five mechanisms are connected to the accident risk:

1. Direct in-car modification of the driving task
2. Direct influence by roadside systems
3. Indirect modification of user behaviour
4. Indirect modification of non-user behaviour
5. Modification of interaction between users and non-users

The second group deals mainly with exposure:

6. Modification of road user exposure
7. Modification of modal choice
8. Modification of route choice

Finally, there is the mechanism that deals with changes in accident consequences:

9. Modification of accident consequences

7 Restrictions of the method

7.1 Limitations

The main restriction of the method is that it needs a special data set, containing accident and victim data disaggregated in a specific way.

7.2 Scalability; extension to real world

The safety assessment is developed in real ITS systems and functions.

7.3 Reliability and risks

Predictions rely very much on the assumptions made and the accident data quality. On the other hand, the method is transparent and false assumptions can be easily corrected.

8 Examples of use

- Socio-economic assessment of cooperative system deployment. CODIA project, Final report.
- Vehicle Safety Systems, eImpact Project. Deliverable D4

Traffic safety

4.9. Safety assessment with Crash Data

1 Short description of the method

The aim of the study is to estimate the impacts of a specific safety system on accident consequences in a certain country (or place). The estimated number of fatalities that could be avoided using the selected safety system is based on the case reports of road accidents published covering a determined period of time.

The study evaluates the potential reduction in crash involvement of cars equipped with the selected specific safety system. The evaluation outcome can be presented in terms of global number of fatalities (or accidents) that could have been prevented with the safety system and/or minimising of damages achieved.

The evaluation should be conducted for all crashes as well as for a variety of road and loss of control conditions, driver gender, impact type and single vehicle crashes. In addition, a study of the selected safety system benefits in terms of crash costs could be undertaken.

2 Context of the evaluation

2.1 Phase – lifecycle of the product / Intelligent Vehicle system

Study with crash data is only suitable when the ITS system is in its full scale implementation cycle time. It is therefore suitable to evaluate the safety impact of the system in the real world.

It can be used to study the effects of the usage of a specific safety system (benefits in terms of avoiding fatalities of a particular safety system). An indirect cost-benefit ratio due to the accidents avoided can be taken into consideration so that the economic benefits of the selected safety system can also be evaluated.

2.2 Expected outcome, research questions

The expected outcome is the effect of a safety system on a full scale level in terms of number of fatalities that could have been prevented and of minimising damages as well as the indirect benefit cost ratio of fitting the safety system in vehicles. The resulting parameters include the relatively rates of crash involvement for cars fitting the selected safety system and not fitting it and a rough estimation about cost-savings calculated based on some assumptions as penetration of the selected safety system in the market.

Research questions can for example be: "How many accidents could be avoided by applying this type of IVS at 100% of the vehicles in this

country?", or "what could be the cost reduction in assurances if this system is fitted in all vehicles?"

2.3 Target group of the outcome (public authorities, manufacturers etc.)

Mainly public authorities, such as cities, regions or national road authorities, also assurance companies could be the target outcome. But also individual users are interested in safety of their car and thus, manufacturers can express interest for this sort of study.

The output in terms of the benefit cost-ratio can be important for decision makers to support further research on IVSS and insurers to enhance the usage of the selected safety system.

2.4 Resources needed

2.4.1 Organisational

A crash study does in most cases not require special organisational resources, as long as the personnel and technical resources are covered, such as software licences and so on. However, in some cases when it is desired to perform a more in depth study, some road accident teams should be composed by different experts such as police officers, doctors, psychologist, etc, apart from technicians.

2.4.2 Personnel

This sort of study mainly requires statistical expertise. If suitable data is available, the analysis is quite straight forward. However, the most effortful part of the method concerns finding the suitable case and control vehicles, which requires special expertise. In ideal comparison they should differ only by availability of the evaluated system, but in reality there are often differences in vehicle types (also improvements in passive safety to be distinguished) and ages, in driver gender and age, and how much the vehicles have driven.

Road accident investigation teams could be needed to study each fatal road accident type. Police officers, road specialists, vehicle specialists, physician and psychologists can be members of these teams. Medical doctors specialized in traffic traumatology could be needed too.

2.4.3 Technical

No specific technical tools are required, apart from those mathematical or statistical tools that can help to calculate or visualized the important data (e.g. excel, SPSS, Matlab). In terms of computational power, usually, a modern pc is sufficient.

2.4.4 Financial

A study with crash data requires relatively modest investments. The only required finances are for the licence costs for the statistical software, computer hardware (normal pc) and for the required manpower and time (some weeks to some months): 1 to 10 man-months.

3 Orientation of the method

3.1 Theoretical / empirical; Ex-ante / ex-post

The orientation is empirical and ex-post, since crash data need to be available.

3.2 Experimental / natural

The method is natural in the sense that it is based on ex-post analysis of a real-world situation and dataset which is totally natural and unobtrusive, since no instrumented vehicles were used (generally, the study uses vehicles where the IVS system was already installed) and drivers were not instructed to participate in a test.

3.3 Background

The method is empirical, based on crashes that already occurred in real-world traffic (often several years to have enough crash data for statistical significance). For a theoretical background can be referred to Evans (Evans, L. 1986: "Double paired comparison- a new method to determine how occupant characteristics affect fatality risk in traffic crashes", *Crash Analysis and Prevention*, Vol.18, No 3, pp.217-227). Also some statistical methods are used and should be described in each particular study.

4 Focus

4.1 Traffic safety

The method is used to compare crash risks among vehicles with and without an ITS system under different conditions. So, the method takes into account impacts on crash risk. Also, as the method evaluates real world data, impacts on crash consequences are taken into account during the study.

Impacts by road user can be calculated with the method if suitable data is available. The method can e.g. differentiate between protected and unprotected road users. However, often in this sort of study, crashes involving vulnerable road users (pedestrians, motor cycles and bicycles) are excluded as they tend to dominate the injury severity of the crash and in general.

Regarding vehicle type, the vehicles should be divided in at least two groups to follow the control method: vehicles where the selected ITS system is fitted and vehicles where it is not. The study can be subdivided in more groups of vehicles if suitable data is available.

Impacts by road type can be calculated with the method, again if suitable data is available. Road accident investigation teams can be composed in order to separate the investigations by road type.

Also an evaluation related to weather condition can be carried out if suitable data is available, such as with a separated analysis by road surface conditions (dry, wet, icy/snow).

Furthermore, extrapolation of data can be done (although the method itself does not require forecasting of accident data) making some assumptions such as (e.g.) that the average decline is linear and amounts to 0.5% for fatalities, 4% for serious and 0.9% for slight casualties (based

on the average decline year on year) to be able to predict the reduction in car occupant casualties, or that the total number of vehicles in a country remains constant some years.

5 Description of the method

5.1 Short description of the underlying principles

Crashes which occur in a certain country or region resulting in injuries or deaths are usually reported and recorded in a public register.

The data collected corresponding to a certain period of time should be matched to vehicle licensing information so that car make, model, variant and year of manufacture was known.

The particular ITS (Safety system) of the study can be matched to the crash data by using data from a Vehicle Identification Checkbook. A subset of this data can be selected to include all injury accidents in which a car was involved. Crashes involving vulnerable road users, whether pedestrians, motor cycles or bicycles, will often be excluded. This subset selection is based on the fact that these vulnerable road users tend to dominate the injury severity of the crash and in general, such crashes are not those where we would expect a major safety system effect.

The analysis uses a case-control method based on the induced exposure method (Evans,L. 1986: "Double paired comparison- a new method to determine how occupant characteristics affect fatality risk in traffic crashes", *Crash Analysis and Prevention*, Vol.18, No 3, pp.217-227). The case-control method compares vehicles including the specific safety system and vehicles non-including the specific safety system in total.

Case vehicles will be defined as those known to be equipped with the selected safety system. A comparable group of control vehicles not fitted with that specific Safety system have to be defined as well. These can be, in general, the previous version of a case vehicle. The make and model of case and control vehicles should be collected and referenced. Every effort should be made to compare cars that were as similar as possible so that the major difference would be the specific Safety System fitment.

The case control method may also require vehicle manoeuvres to be separated into those where the specific safety system could have had an effect and those where no safety system effect is assumed.

5.2 Type of assessment (desktop, lab, simulator, field, statistics)

A crash data study is a desktop study, which can be performed on a normal pc taking into account published information such as accident reports and vehicle identification checkbooks.

5.3 Process/design

5.3.1 Test persons

The method does not require test persons.

5.3.2 Sample size

The sample size in these sorts of studies is limited by the available information in terms of accidents and vehicle information related possible to match. In order to draw statistically significant conclusions, the number of available accidents should be large enough.

5.3.3 Set-up, design

First the road accident data with real-world data is collected from a recorded published report.

Then information on the particular IVS of the study has to be matched with the accident data, using data from the Vehicle Identification Checkbook.

Subsets of the total amount of data can be made in order to exclude information that could dominate the severity of crashes where we would not expect a major safety system effect.

A team of road accident investigators could be composed in order to perform a more in-depth study and to centre the study depending on a classification. Police officers, road specialists, vehicle specialists, physician and psychologists can be members of these teams. Medical doctors specialized in traffic traumatology could be needed too.

5.3.4 Measuring or technical equipment

The required equipment is a (normal) pc suitable for the desired statistic software tools (e.g. excel, Access, SPSS, Matlab).

5.3.5 Data requirements

Required data are the real world national road accident reports (accident statistics) recorded in every country per year or per certain period of time, and the vehicle identification checkbooks to be able to match the data, meaning the fitment of the selected safety system in the vehicles.

Also interviews and surveys of emergency centres duty officers can be used for a more in-depth study, in order to understand the accident processes and causes.

5.4 Expertise needed

The required expertise is expertise on using mathematical or statistical methods or tools to perform an analysis of the different effects of a selected ITS system on safety in terms of decreasing accidents or fatalities or minimising the different possible damages or injuries in an accident.

For a more in-depth study based on crash data, also traffic safety and medical knowledge can be useful. Police officers, road specialists, vehicle specialists, physicians and psychologists can be members of composed road accident investigation teams. Medical doctors specialized in traffic traumatology could be needed too.

6 Results

6.1 Type of output

The method evaluates the potential reduction in crash involvement of cars equipped with the selected specific safety system. The evaluation can give output in terms of global number of fatalities (or accidents) that could have been prevented with the safety system (quantitative) and/or minimising of damages achieved (qualitative)

Also more advanced analysis can be done with additional methods or statistical analysis and reported in graphics, numbers and text.

This study can also give figures as input for the benefit cost-ratio

6.2 Parameters / description

The evaluation should be conducted for all crashes as well as for a variety of road and loss of control conditions, driver gender, impact type and single vehicle crashes.

Also an indirect cost-benefit ratio due to the accidents avoided or the crash costs reduction can be an outcome, so that the economic benefits of the selected safety system could be specified.

7 Restrictions of the method

7.1 Limitations

Restrictions of the method can be the probable change in number of fatalities/injuries.

A large amount of accident data is needed, with and without the system, and separated for different road types, driver types etc. Often these data is not available.

Also, the ITS system should be in its full scale implementation cycle time and a sufficiently large amount of vehicles needs to be equipped with the system already.

In a more in depth study, whether a person's life could have been saved with faster help can only be estimated.

7.2 Scalability; extension to real world

Studies with crash data are based on real world data. In order to extrapolate the estimated accident reductions, assumptions as penetration of the selected safety system in the market should be made. In this sense, it is important that the set up covers different traffic situations (e.g. different traffic demands, penetration rates, road types) to be able to forecast the effects for future penetration rates, vehicle fleets and traffic demands.

Upscaling the results from a country up to EU-25 level is not common, but theoretically possible, however, the problem for this is the (lack of) data availability on EU level.

7.3 Reliability and risks

The final figures are usually extracted making some assumptions, so that the reliability of the method is not 100%, and in this sense, the obtained figures can not be taken into account as absolute truth.

The assumptions to be made, such as (e.g.) penetration of the selected safety system in the market in a certain period of time, average (linear) decline of accidents per year or that the total number of vehicles in a country is assumed to remain constant in some years in order to extrapolate data, make that a 100% reliability of the results cannot be guaranteed. However, it is possible to derive confidence limits or similar error margins for the impact estimates.

The reliability will depend on both the quality of the accident data used and the accuracy of the vehicle identification checkbook used to match the data. Every effort should be made to compare cars that were as similar as possible, so that the major difference will be the specific safety system equipment. However, in practice it will not be possible to compose such perfectly comparable cases. This adds a little uncertainty to the results.

One important factor to consider when viewing results of this sort of study is the part played in injury reduction due to improvements in passive safety of the cars. There is no indication that passive safety improvements change driving behaviour that would influence the risk of crash involvement, but the improvements could be expected to change injury outcomes. Whilst the reductions in killed and seriously injured occupants will represent the combined effects of reduced crash involvement and reduced injury risk, a passive safety system would be expected to give the same protection on a wet as a dry road under the same crash conditions, yet there are very different risks of fatal and serious crashes in the data reported. Although it is not easily possible to quantify the effects of passive safety improvements, the results in this type of study are considered largely to be a measure of improvements in handling performance.

Nevertheless, as the basis is real world data, the method can be considered as sufficiently reliable.

8 Examples of use

- Frampton R., Thomas P. (2007). Effectiveness of Electronic Stability Control Systems in Great Britain. Loughborough University. <http://www.dft.gov.uk/pgr/roads/vehicles/vssafety/safetyresearch/esc/>. This report has evaluated the reduction in crash involvement of cars equipped with Electronic Stability Control (ESC) systems. The evaluation has been conducted for all crashes as well as for a variety of road and loss of control conditions. In addition, a study of ESC benefits in terms of crash costs and accidents prevented has been undertaken. The results show that ESC effectiveness is 7% in crashes of all severity. Serious crashes are 11% lower compared to non ESC cars and fatalities 25% lower. The potential savings in accident costs for a 100% take up of ESC amounts to some 959 million pounds by preventing some 7800 crashes. Even at a 50% take up the saving amounts to some 480 million pounds.
- Virtanen N. (2005). Automattisen hätäviestijärjestelmän vaikutukset onnettomuustilanteessa [Impacts of an automatic emergency call

system on accident consequences]. AINO-publications 14/2005. ministry of Transport and Communications, Helsinki.
http://www.aino.info/julkaisut/4_kuljtuki/aino14_2005.pdf/

The aim of the study was to estimate the impacts of an automatic emergency call system (eCall) on accident consequences in Finland. The estimated number of fatalities that could be avoided using the eCall system is based on the case reports of Road Accident Investigation Teams covering the period 2001–2003. The eCall system could very probably have prevented 4.7% of the fatalities in accidents involving motor-vehicle occupants. In the accidents involving fatal unprotected road user, however, the system could probably have prevented no fatality. In all, eCall system was estimated to be able to reduce 4–8% of road fatalities and 5-10% of motor-vehicle occupant fatalities in Finland. The benefit-cost ratio of the eCall system examined in this study was 0.5–2.3. The benefit-cost ratio would have been higher if the indirect benefits of the eCall system could have been taken into account.

Environment

4.10. Emission modelling

1 Title and short description of the method

Emission models

Traffic emission models estimate traffic emissions or changes in emissions when the vehicle fleet or its activities change. The change in emission rates can be derived by using micro- and macro-traffic simulation models. For example instantaneous emission models provide a precise description of vehicle emission behaviour to the dynamics of driving patterns, and can therefore be used to explain some of the variability in emissions associated with given average speeds. The emissions are calculated for any vehicle operating profile, and thus also the vehicle profiles produced by micro-simulation traffic models can be used. On the contrary, emission models based on macro-simulation estimate a change in fuel consumption and resulting emissions from the change in average speeds observed in the network.

Also a functional relationship connecting average speeds and emissions can be used to estimate the environmental impacts of IVS. Input data for this relationship can be gathered by recording vehicle speed data inside or outside the vehicle.

2 Context of the evaluation

2.1 Phase – lifecycle of the product / Intelligent Vehicle system

Emission models using micro- and macro simulation models are especially suitable in early phases of the product development life cycle of the IVS (idea and plan phase). Furthermore, simulation tools can also provide complementary data to a pilot or a large-scale demo. In a pilot or demo, usually only a few vehicles are equipped. Therefore emission models based on simulations can generate additional data showing the impact on emissions if larger penetration rates or different traffic situations are assumed than the one prevailing during the pilot or the demo of the IVS.

Emission models applying empirical data can be used mainly in large-scale demos and during the full-implementation phase of the development lifecycle when a huge amount of empirical data is available.

2.2 Expected outcome, research questions

Results of emission models provide some data about possible environmental impacts of IVS to decision makers. The results could be used as a first indication about the performance of an IVS with respect to emission savings.

2.3 Target group of the outcome (public authorities, manufacturers etc.)

The environmental impact assessment shown by emission models can provide public authorities first data about how a specific IVS can contribute to emission reduction. Thus some input for decision making on how to

distribute public funds on research development expenses in the field of environmental impacts of traffic is provided.

The results can also provide data to manufactures / suppliers about the environmental performance of the IVS, to fulfil the emission standards for vehicles. For vehicles for which the environmental performance is increased by a specific IVS, this information can be used also for the promotion strategy to influence purchase decisions of vehicle drivers interested in "green mobility".

2.4 Resources needed

2.4.1 Organisational

The method does not require special organisational resources.

2.4.2 Personnel

For simulation based emission models, experience in simulation and some expertise on vehicle emissions is necessary. Interpreting (random) values of simulation runs requires furthermore statistical expertise.

If empirical data in emission models is applied, experts in statistics are needed for data analyzing. Also personnel for installation of data recording systems are needed.

2.4.3 Technical

For simulation based emission modes, a traffic simulation model is needed (e.g. Vissim, SISTM), as well as computers with sufficient computational power. Normally, a modern PC is sufficient. Also some additional tools or software packages may be used to analyse the data (e.g. excel, SPSS, Matlab).

For gathering of empirical data, sensors and measuring instruments are needed, such as induction loop detectors for measuring traffic flows, or radar to measure traffic speeds.

2.4.4 Financial

Emission models based on simulation require relatively modest investments. The only required finances are for the licence costs for the simulation model (sometimes up to 10000 euro's), computer hardware (normal PC) and for the required manpower and time (some weeks to some months).

Using empirical data by equipping vehicles or the infrastructure with data sensors and measuring instruments will noticeable increase the costs of emission models compared to using simulation tools only.

3 Orientation of the method

3.1 Theoretical / empirical; Ex-ante / ex-post

In principle, the method is theoretical, but empirical data can be used as input data and to calibrate the simulation models according to real-life situations of traffic.

3.2 Experimental / natural

The method is experimental if the traffic situation is simulated, but can also be partly naturalistic if empirical data is used. The construction of a simulation model has to cover all relevant aspects of real traffic situations to generate meaningful results.

3.3 Background: theoretical, practical

The method is theoretical: It is based on mathematical models and uses algorithms to calculate the results.

4 Focus (choose the relevant ones and utilize the criteria from expert enquiry)

4.1 driver behaviour
not relevant

4.2 traffic flow and efficiency
not relevant

4.3 Traffic safety
not relevant

4.4 Environment

Emission models based on simulations take the output from a traffic simulation model and evaluate the emissions for example of NO_x, PM, total carbon (C) and CO₂ as a result of the IVS being studied. In more aggregated macro simulation models the emissions are calculated based on average speeds and flows using average emission factors. Instantaneous emission models use the outcome of micro-simulation about individual driver behaviour, such as speeds and accelerations per second (or 0.1 second), such that detailed emission calculations are possible.

5 Description of the method

5.1 Short description of the underlying principles

Emission models based on simulations require detailed and precise information on vehicle operation (e.g. speed, acceleration, headway). Since direct field measurements to gather these data are possible but represent a logistically large exercise, it is easier to use traffic simulation modelling. The simulation models then simulate driving patterns at an individual vehicle level or average speeds on an aggregate level by using mathematical rules. Micro simulation usually is applied for the assessment of local effects of an IVS on the level of a small network or a corridor. Emission effects on a regional or national scale may be better derived from macroscopic emission models or total fuel consumption.

5.2 Type of assessment (desktop, lab, simulator, field, statistics)

An environmental assessment with a simulation emission model is a desktop study using a PC and software tools. However, to calibrate the

models, some real-world measurement data from a field-operational test is often used.

5.3 Process/design

5.3.1 Test persons

The method does not require test persons.

5.3.2 Sample size

Microscopic traffic simulations are based on stochastic processes; different runs produce different results; variability of data between different runs can be described by statistical concepts such as standard deviation.

In order to be able to draw statistically significant conclusions, several simulations runs of the same scenario are usually done, usually 5 or 10 (depends on the variability of the output values). The resulting values are averaged from the separate simulation runs.

5.3.3 Set-up, design

First the technical and functional specifications of the selected IVS systems are translated into descriptions of vehicle and driver behaviour, which is then implemented in a traffic simulation model. The scenarios that will be evaluated have to be determined and implemented (e.g. different penetration rates of the IVS, levels of service, etc.). The emission model has to be fed with the speed and acceleration patterns as outcomes of the simulation model or as empirical data. These outcomes can differentiate according to parameters like vehicle type and size, technology level of vehicle, road type, fuel type etc. Using the outcome of the traffic simulation for different traffic scenarios (e.g.) then the emissions of grams per pollutant per vehicle kilometres is derived. In the final step these emissions can be scaled up to the EU level.

5.3.4 Measuring or technical equipment

A simulation traffic model is needed (e.g. VISSIM, SISTM), as well as computers with sufficient computational power. Normally, a modern PC is sufficient. Also some additional tools or software packages may be used to analyse the data (e.g. excel, SPSS, Matlab).

For gathering of empirical input data sensors and measuring instruments are needed.

5.3.5 Data requirements

Data on vehicle operation and location is needed. These are e.g. given by traffic counts (per vehicle category) and speeds / accelerations at several locations in the network. Also information about infrastructural features like road type is needed. For upscaling results to assess the impact on emissions across the EU level, traffic flow data and data about the composition of vehicle fleet and vehicle fleet kilometres are needed. For forecasting the emission levels, a forecast of the vehicle fleet and vehicle fleet kilometres has to be done.

5.4 Expertise needed

Experience in simulation and some expertise in vehicle emissions and emission models are necessary to apply the simulation based emission models. Interpreting (random) values of simulation runs requires furthermore statistical expertise which is also needed if empirical data are integrated in the emission models.

6 Results

6.1 Type of output

The output is emissions in gram per vehicle and per kilometre; also the percentage change relative to the base case at different equipment rates of IVS can be shown.

6.2 Parameters / description

The parameters influencing emission levels can be vehicle-related and operational parameters. Vehicle related parameters are e.g.:

- Vehicle category (cars, vans, HGVs, buses)
- Vehicle size
- Fuel type
- Technology level
- Mileage.

Operational factors are e.g.

- Speed
- Acceleration
- Gear selection
- Road gradient
- Traffic density
- Congestions.

7 Restrictions of the method

7.1 Limitations

The results of the emission models depend critically on the simulation results and therefore on the realism of the simulation model. A simulation model covers a set of parameters and scenarios which are considered as relevant for description of the considered traffic situation. Thus not all features of real-world traffic situations are incorporated into the model. However, using a calibration procedure based on validated empirical data will increase realism of the model and representativeness of results.

A further limitation arises because for micro-simulation models which can be performed only for representative network sections, considering the total road network would require a very large computational time and a very complex calibration of traffic data. Thus micro-simulation is typically restricted to a representative number of traffic scenarios.

7.2 Scalability; extension to real world

The results of the emission models depend critically on the simulation results. Therefore the simulation model determines whether the emission results can be transferred or generalized to other traffic situations. If the

simulation is set up to different scenarios that cover a broad set of different traffic situations (e.g. different traffic demands, penetration rates, road types) then transfer to real-world traffic situation is possible.

Upscaling the results to the country or to EU level is also possible, but difficult because the problem of data availability on a national level can arise. Data which are needed are e.g. vehicle kilometres per road type, and differences in vehicle fleets and driver behaviour between countries.

7.3 Reliability and risks

The results of the emission models depend critically on the reliability of the simulation results, and, if used, on the validity of the empirical data. The speed and acceleration behaviour is not always very accurate, since these models were originally developed for traffic efficiency studies, for which this is not as critical as for emission calculations. To get insight into and to improve the accuracy of the speed and acceleration behaviour of the simulation model for a certain traffic situation, a calibration and validation study can be done with real-world measurements (e.g. video), or information from previous validation studies can be used.

Also, to derive indicators of the reliability of the results, confidence limits or similar error margins for the impact estimates, based on several simulation runs can be calculated. Since the simulations are based on stochastic processes, different runs produce different results. Thus by increasing the number of runs, the likelihood of various outcomes can be more accurately estimated.

8 Examples of use

8.1 CODIA, Co-Operative systems Deployment Impact Assess, Final study report, Deliverable 5, 2008

The CODIA study was funded by the EC DG Information Society and Media (running: 2008). Its goal was the assessment of direct and indirect impacts, costs and benefits of five co-operative systems (Speed adaptation due to weather conditions, obstacles or congestion (V2I and I2V), Reversible lanes due to traffic flow (V2I and I2V), Local danger / hazard warning (V2V), Post crash warning (V2V), Cooperative intersection collision warning (V2V and V2I).

In the study Instantaneous emissions model used the output from a traffic simulation model to evaluate the emissions of oxides of nitrogen (NO_x), particulate matter (PM) and total carbon (C). The latter was converted later to carbon dioxide (CO₂). Changes to all three quantities were calculated as a result of the cooperative systems being studied.

8.2 ADVISORS, Action for Advanced Drivers Assistance and Vehicle Control System Implementation, Standardisation, Optimum Use of the Road Network and Safety

The ADVISORS study was funded by the 5th Framework within the European Competitive and Sustainable Growth Program (running: 4/2001 – 12/2003). Its goal was to develop a methodology to

assess the impact of different types and different levels of penetration of advanced driver assistant systems (ADAS). The SISTM (United Kingdom) and HUTSIM (Finland) micro-simulation models are used to estimate the environmental impacts of the introduction of ADAS. The results of the study describe the impacts on the emission types CO, CO₂, NO_x and PM depending on different penetration level of ADAS in the vehicle fleet.

Environment

4.11. Air quality monitoring

- 1 Title and short description of the method
Air quality monitoring

With air quality monitoring, the air quality is measured continuously or frequently at one or several locations with measuring instruments for e.g. CO₂, NO_x or with particle counters for particulate matter (PM10).

Air quality monitoring can be used to evaluate the effect of IVS on air quality. To determine the effect in relation to the IVS, also the number of passing vehicles equipped with the IVS and the use of the IVS has to be monitored, e.g. with instrumented vehicles.

- 2 Context of the evaluation

- 2.1 Phase – lifecycle of the product / Intelligent Vehicle system

For applying the method to evaluate the effect of IVS on air quality, a pilot with the IVS is needed; thus, the method will be applied in the more “late” phases of the development lifecycle.

- 2.2 Expected outcome, research questions

The outcome is the change in concentrations of the measured gases or particles, in relation to the use of the IVS.

- 2.3 Target group of the outcome (public authorities, manufacturers etc.)

National, regional and cities can use air quality monitoring to check the air quality against the air quality norms and to test how IVS can improve the air quality to reach a value below the norms, when necessary.

This can also give useful information for manufacturers, e.g. on how their systems can be tuned to improve fuel efficiency.

- 2.4 Resources needed

- 2.4.1 Organisational

Next to the organisation of a FOT with the IVS of study, measuring instruments need to be installed, maintained and the output stored and analysed. It requires organisational effort to find the right measuring equipment (e.g. outsourcing to a specialist company), find the right location and to organise the installation, design and implementation of the experimental set-up (e.g. before and after measuring period) and arrange permissions to perform the measurements. Furthermore, a long measuring period is needed to determine the effect on air quality, since other (not controllable) factors disturb the measurements, such as wind power and direction.

- 2.4.2 Personnel

Since different types of specialist measuring instruments can be used, several experts with very specific expertise on those measuring instruments and air quality knowledge are needed. Also, statistical analysis is needed for the analysis.

2.4.3 Technical

Regarding the air quality monitoring instruments, this concerns very specialist and costly equipment. For different gases and particle sizes, there exist different types of measuring instruments which are able to whether or not to measure in real-time or with different frequency and accuracy. Some instruments (for particulate matter) e.g. work with the principle of light reflection, others with the weight of particles caught in a filter.

To get a good insight in the effect of the traffic on air quality, not only the air quality itself, but also driving characteristics and vehicle types need to be monitored accurately. For this, detection loops and cameras (e.g. with license plate recognition to get accurate information on vehicle and engine type) can be used.

2.4.4 Financial

The required measuring instruments are generally very expensive. Furthermore, they need to be used and maintained for a long time. Also the required manpower is high. This is therefore a costly method (in ongoing research, it is investigated how the air quality and traffic can be monitored with less measuring instruments, while still attaining the required accuracy).

3 Orientation of the method

3.1 Theoretical / empirical; Ex-ante / ex-post

Empirical (real-world measurements), ex-post with before (without IVS) and after measurements (with IVS).

3.2 Experimental / natural

The method is natural: real-world driver behaviour is measured. The method is unobtrusive, when the measuring instruments are not (obviously) visible, and therefore does not influence the driving behaviour.

3.3 Background

The theoretical background concerns chemical and physical processes of vehicle emissions (for the different gases and particulate matter) and emission propagation (dependent of weather variables). Also, knowledge of how vehicle behaviour is related to vehicle emissions, such as how acceleration behaviour is related to higher emissions, are important for a good assessment of the impact of traffic and IVS on emissions.

Furthermore, the analysis of the measurements is based on specific theoretical principles, such as image processing techniques when video cameras are used.

4 Focus (choose the relevant ones and utilize the criteria from expert enquiry)

4.1 Environment

Emissions monitoring is used to assess the effects on the environment.

Impacts on e.g. fuel consumption, CO₂, NO_x, SO₂, particulate matter (PM), HC, secondary emissions generated by chemical reactions in the atmosphere like ozone, noise, can be measured and assessed. There can be differentiated between road types (e.g. urban, non-urban) by choosing the measurement locations. The effect of varying traffic intensities can be taken into account when this is measured, e.g. with loop detectors. Also, the effect on air quality of different vehicle (passenger car, truck), engine (e.g. diesel, gasoline) and Euro (Euro1 to Euro5) types and vehicle age can be assessed, when this is monitored (e.g. with license plate recognition). Vehicle types can be estimated from the vehicle length with loop detectors.

5 Description of the method

5.1 Short description of the underlying principles

With air quality monitoring, the air quality is measured continuously or frequently at one or several locations with measuring instruments for e.g. CO₂, NO_x or with particle counters for particulate matter (PM₁₀). To be able to measure the traffic emissions for all wind directions, measuring instruments need to be placed close to the road and on both sides of the road.

Air quality monitoring can be used to evaluate the effect of IVS on air quality. To determine the impact on emissions in relation to the IVS, a 'Before' and 'After' study can be carried out, or a distinction need to be made for vehicles with and without the IVS in the passing traffic. The number of passing vehicles equipped with the IVS and the use of the IVS can be monitored, e.g. with instrumented vehicles or cameras. Driving characteristics with and without the implementation of the IVS can be measured e.g. with loop detectors or cameras. The emissions can be evaluated for various vehicle categories and Euro standards to reflect the varying emissions for different vehicle types.

5.2 Type of assessment (desktop, lab, simulator, field, statistics)

This method is a field test, since it is based on real-world measurements. The analysis afterwards furthermore requires a statistical analysis.

5.3 Process/design

5.3.1 Test persons

No test persons are needed if the IVS is present on the road in part of the vehicles, and if this can be detected. In case the IVS is not yet on the market, the emission monitoring needs to be combined with a FOT, which needs test persons to drive the test vehicles (see method description of large-scale field study).

5.3.2 Sample size

The sample size is determined on the one hand by the length of the period that the measurements are done, and on the other hand by the number of passing vehicles with the IVS of study.

It is hard to determine beforehand how long the measurement period should be. This depends among others on the weather conditions. The

desired weather conditions should have a wind direction from the traffic on the road to the measuring instrument next to the road, and a wind speed strong enough to blow the emissions to the measuring instrument, but not too strong to spread the emissions in the air too much. Also, rain will influence air quality measurements, especially for particulate matter. The wind direction condition can be solved by using measuring equipments on both sides of the road.

When the right weather conditions are present, already one day will give valuable insights, but usually much longer periods are used, up to one year. Also, to be able to isolate the effect of the IVS, the traffic flows should be almost constant during the measurement period. A longer measurement period could be needed to find enough comparable traffic conditions.

Concerning the required sample size for vehicles with the IVS for air quality monitoring, we did not find examples in existing studies, but an estimation would be that at least 10% of the vehicles need to be equipped during a certain measurement period (e.g. per 15 minutes) to be able to measure the impact with statistical significance.

5.3.3 Set-up, design

First, the measurement location, type of measurements, indicators to be measured and measurement period need to be chosen. Next, the specific measurement instruments (with different measuring technologies, costs, accuracies and measurement frequencies) and exact positions of the measuring instruments have to be chosen. As said before, it is better to measure the air quality on both sides of the roads to be prepared for more wind directions.

Next to air quality, also the traffic characteristics need to be monitored. Some monitoring instruments might already be present, such as loop detectors in the road. To get the best information on vehicle types, video cameras can be used.

5.3.4 Measuring equipment

Regarding the air quality monitoring instruments, this concerns very specialist and costly equipment. For different gases and particle sizes, there exist different types of measuring instruments which are able to measure concentrations of gases or particles, whether or not in real-time or with different frequency and accuracy. Some instruments (for particulate matter) work with the principle of light reflection, others with the weight of particles caught in a filter, and can therefore only be measured after longer measurement periods, e.g. at the end of each day. The air quality monitoring instruments furthermore need electrical power, which can be generated from an aggregate when necessary. Sometimes the available power from road lightning or traffic lights can be used.

To get a good insight in the effect of the traffic on air quality, not only the air quality itself, but also driving characteristics and vehicle types need to be monitored accurately. For this, detection loops and cameras

(e.g. with license plate recognition to get accurate information on vehicle and engine type) can be used.

5.3.5 Data requirements

Both the air quality and traffic measurements needs to have sufficient accuracy and measuring frequency. Depending on the research questions and the type of IVS, this can e.g. be per day (when exceedence of daily air quality norms is checked), or for a much smaller period such as per 5 minutes. Usually IVS influence driving characteristics at a very detailed level, therefore to evaluate the impact of these, small time and space resolution measuring instruments are needed, both for the air quality as for the driving and traffic flow characteristics. There exist air quality measuring instruments that measure at a frequency of 4 to 10 Hz, and cameras which take a picture of the traffic also at 10 Hz. Usually, a resolution of 1 Hz is more than enough for IVS impact assessments. From this, accurate averages over 5 or 15 minutes can be determined.

5.4 Expertise needed

A lot of different expertises are needed: experience with setting up field tests with air quality and traffic monitoring, expertise on air quality monitoring instruments and traffic monitoring instruments, experience with FOTs when the test is combined with a FOT, knowledge of the chemical and physical properties of the measured gases and experience with the analysis of the different data sources. Synchronising and interpreting all these data sources is a complex and time consuming process, which will be done largely manually, with the help of different software packages such as Matlab. Furthermore, analysing the camera images can be done with sophisticated video imaging techniques, which also requires expertise on the specialistic software and analysing techniques. Also, some statistical expertise is needed.

6 Results

6.1 Type of output

Usually, in an air quality monitoring study, the output is the percentage change in emissions of several gases or particulate matter, measured for intervals of a certain length, usually per hour, per day or per year. This can be linked to hourly, daily and yearly air quality norms.

6.2 Parameters / description

Examples of parameters that can be measured in an air quality monitoring study, are:

- Percentage change of CO and CO₂ and link to fuel consumption
- Percentage change of NO_x, NO₂, SO₂ and HC
- particulate matter (PM) emissions of diesel fuel
- Weather variables such as wind speed and direction, needed for interpretation and further analysis with concentration models
- noise levels (dB(A))
- Impacts on further emissions of diesel fuel like lead (Pb) and benzene
- Impacts on secondary emissions like ozone

There can also be differentiated between road types (e.g. urban road, motorway, intersection), when measurements are done at different locations with different road types, and for various vehicle categories and Euro standards to reflect the varying emissions from different vehicle types of varying ages.

7 Restrictions of the method

7.1 Limitations

Main limitation is that the method is costly and time consuming and requires a lot of expertise (however, it will provide a lot of valuable insights related to traffic in relation to air quality). Also, a lot of manual post-processing is needed for synchronising and analysing the different data-sources. Therefore, real-time monitoring is not yet possible, let alone forecasting.

Furthermore, vandalism can be a problem for the costly equipment (especially when drivers think that their speed is monitored for enforcement purposes).

7.2 Scalability; extension to real world

An air quality monitoring study reflects the real-world already, since it concerns real-world measurements.

Scalability to regional, national or EU level or translation of the results to other locations is however very difficult, since the effects very much depend on the local traffic situation, such as vehicle fleet, speed limits, traffic light control etc.

7.3 Reliability and risks

When the available time is short, it could be that the traffic and weather circumstances during the monitoring period are not suitable for a good impact assessment. Also, a lot of different indicators (both air quality and traffic) need to be measured with high accuracy to be able to draw good conclusions. Often, not enough traffic variables are measured (e.g. vehicle types are unknown) or with a too low resolution (e.g. per hour) to capture the small changes in driving behaviour from the IVS, needed to assess the impact on emissions.

There are however measuring instruments available with sufficient accuracy and frequency, so when applied correctly, the method will be very accurate and reliable.

8 Examples of use

- ATM Monitoring and Evaluation. Active Traffic Management on the M42 motorway UK, Monitoring and Evaluation Report. Doc/1807/V3, 2008. <http://www.dft.gov.uk/pgr/roads/tpm/m42activetrafficmanagement/>

Socio-economy

4.12. Cost benefit analysis (CBA)

1 Short description of the method

The potential benefits and costs of an Intelligent vehicle system (IVS) are estimated across a set of impacts. The impacts e.g. in the field of accident prevention, travel time, emission reduction and driving comfort are converted into monetary terms by multiplying impact units by cost-unit rates per unit. By comparing the benefits of the considered IVS with its costs including in-vehicle system costs, maintenance/operation and infrastructure costs the efficiency of the IVS is evaluated.

2 Context of the evaluation

2.1 Phase – lifecycle of the product / Intelligent Vehicle system

For a CBA a specification of the functionalities of the system and of the possible use cases are needed. Thus a prototype can be sufficient for a first estimation of costs and benefits. But the range of possible CBA results will then be relatively large. Thus, CBA is more suitable when pilot test results are available and impacts (e.g. avoided fatalities, injuries) can be estimated for example by using an expert survey or a simulation study. The validity of the impact estimation will be further increased if also empirical data from a large-scale demo or full-scale implementation are available.

The method can also motivate decisions to either continue or stop a system development based on the CBA results of the pilot test or a prototype.

2.2 Expected outcome, research questions

Results of CBA can inform policy decision makers about the social profitability of IVS, i.e. whether the benefits in road safety and traffic flow outweigh the costs of the system. This information can be useful to decide about further public supported research in IVS. For example, decisions about the set-up of field operational tests to get more accurate and reliable data about safety and traffic effects of IVS can be influenced by CBA results, and also decisions on research grants which support further technical development of IVS. In general, CBA results on IVS can provide, besides political and legal reasoning, foundation for distribution of public funds to reach goals in road safety and traffic management.

2.3 Target group of the outcome (public authorities, manufacturers etc.)

Benefit-cost ratios show on a highly aggregated value the socio-economic profitability of an Intelligent Vehicle System. Results can be important for decisions makers such as road authorities e.g. to support further research and to support market introduction of IVS. Since in a CBA the complete set of impacts of the system for society should be covered, results are not of direct relevance for purchasing decisions of consumers and investment decisions of manufactures. However, support of market introduction of IVS by public authorities based on CBA outcome can have a positive influence on long term investment decisions of manufacturers.

2.4 Resources needed

2.4.1 Organisational

CBA does not require special organisational resources.

2.4.2 Personnel

Expertise in economics is needed for cost estimation and monetarisation of impacts. Expertise and experience is also necessary for accident and traffic data analysis and in field studies for the evaluation of generated data.

2.4.3 Technical

Beside software tools for data analyses and calculations (e.g. excel, SPSS) no special tools or software packages are needed.

2.4.4 Financial

Beside financial outlays for required manpower no investments necessary.

3 Orientation of the method

3.1 Theoretical / empirical; Ex-ante / ex-post

The method is theoretical since benefits and costs are based on desk top research; empirical results of e.g. field studies and expert surveys are used, but no empirical research is done. Benefit cost ratios can be calculated by using forecasts of impact and costs data (ex ante) or by using historical data (ex post).

3.2 Experimental / natural

The method can be based on both results of an experimental or naturalistic research design. For example, the assessment of safety effects can be based on empirical results of field operational tests. If traffic flow impacts are generated by simulation studies then an experimental research design is used for assessment.

3.3 Background

The method is based on (neoclassical) welfare economics. By using a CBA the efficiency rule is applied for public decision making. From a very theoretical point of view this approach evaluates economic effects of new technologies like IVS by measuring variations in the use of resources of the society. The costs of the technologies in question are then confronted with its possible productive effect for the overall economy (its benefits). The valuations of benefits can be based on willingness-to-pay or cost-unit rates for savings of resources due to the impacts of IVS.

4 Focus (choose the relevant ones and utilize the criteria from expert enquiry)

4.1 driver behaviour

not relevant (suitable for all focus areas)

4.2 traffic flow and efficiency
not relevant (suitable for all focus areas)

4.3 Traffic safety
not relevant (suitable for all focus areas)

4.4 Environment
not relevant (suitable for all focus areas)

5 Description of the method

5.1 Short description of the underlying principles

The CBA compares the potential economic benefits of an IVS, with all relevant consumption in resources due to the implementation of the IVS. All the benefits and the costs are measured in monetary terms by multiplying the physical impact units, for example avoided injuries, with the accordant monetary values.

Mostly, market prices are not available for impacts, such that alternative concepts are used for economic evaluation. These alternative cost-unit rates can be based on a subjective or an objective approach. The subjective approach is based on individual evaluations expressed in monetary terms of a change e.g. in health risks. The objective approach is differentiated into the cost-of-damage approach and the cost-of-avoidance approach. Both approaches use objective cost-data. In the cost-of-damage approach, costs for restoring health and possible productive losses caused by illnesses are calculated and in the cost-of-avoidance approach the costs of the measures to avoid the injury are determined. Because it is often more easy to calculate the costs of the damage than costs of a hypothetical measure to avoid the damage, mostly the cost-of-damage approach is applied.

The CBA can be used to assess absolute efficiency and relative efficiency. A road safety measure is (absolute) efficient if implementation produces positive net benefits. When different road safety measures are compared to reach a safety goal, CBA can provide a ranking according to the level of net benefits generated by the different measures (relative efficiency).

5.2 Type of assessment (desktop, lab, simulator, field, statistics)

CBA is a desktop study. However, data coming out of field studies are often used for impact estimation in the field of safety and traffic flow. Also simulation results on changes in traffic flow (e.g. average speed, traffic density) are used as input for estimating changes in fuel consumption and emission levels.

5.3 Process/design

5.3.1 Test persons

The method does not require test persons.

5.3.2 Sample size

For impact estimation in the field of safety and traffic flow, CBA uses results of different methods. For considerations about statistical evidence of these methods we refer to the description of these methods in the catalogue.

5.3.3 Set-up, design

The set-up is shown for the CODIA study as an example of a typically CBA:

The assessment starts with a specification of the IVS, its functions and possible use cases. Based on these use cases, accident types were identified which will be addressed by the IVS by having an impact on the number of accidents and accident severity.

The safety impact assessment then proceeds by estimating the safety effect of each IVS based on existing knowledge with references found in literature and other evidence available.

The safety effect estimates are then applied to the EU-25 road accident data utilising the forecasted safety trends up to 2030 to provide estimates about the effects of the systems in terms of fatalities, injuries and accidents saved by the systems in 2020 and 2030. For the estimation of the safety effects also forecasted penetration rates of IVS in the vehicle fleet and the corresponding vehicle kilometres driven by IVS-equipped vehicles in 2020 and 2030 are used.

The traffic impact assessment focussed on effects on journey times at different system penetration rates by using micro-simulation modelling. The journey times produced in the simulation runs are converted into vehicle hour changes on an EU-25 scale.

The emission effect assessment utilised instantaneous emission models describing vehicle emission behaviour by relating emission rates to vehicle operation, working also with the outputs of the simulation runs. Emission changes in terms of grammes of pollutant per vehicle kilometres are generated for different scenario and upscaled to the EU-25 level.

Finally, cost-unit rates are applied to the estimated impacts of the IVS (safety, travel flow, emissions) to get the benefits. Given estimations about vehicle fleet and penetration rates of IVS in the total fleet, costs are calculated and benefit-cost ratios calculated as indicators of socio-economic profitability of the considered IVS.

5.3.4 Measuring or technical equipment

Beside software tools for data analyses and calculations (e.g. excel, SPSS) no special tools or software packages are needed.

5.3.5 Data requirements

Base data are accident data (injuries, fatalities, accidents), traffic data (vehicle stock, vehicle kilometres), and penetrations rates of IVS into the vehicle fleet. The data are extrapolated for example to 2020 to get a forecast about the impacts of IVS.

To get the safety and traffic impacts on the EU level the estimated safety (share of avoided accidents) and traffic effects (travel time reductions) of the IVS are applied to the base data.

5.4 Expertise needed

Expertise in economics is needed for cost estimation and monetarisation of impacts. Expertise and experience is also necessary for accident and traffic data analysis and in field studies for the evaluation of the generated data.

6 Results

6.1 Type of output

The discounted benefits and costs of the IVS are measured in monetary values (Euro). As (quantitative) indicator of efficiency the benefit-cost ratio (BCR) is used.

6.2 Parameters / description

The following classes are used for qualifying the benefit-cost ratios: If the BCR is in the range $0 < BCR < 1$ the BCR is rated "poor" showing the socio-economic inefficiency of the IVS; if the BCR is in the range $1 \leq BCR < 3$ the BCR is rated "acceptable" meaning that the social benefits associated with the implementation of a safety system exceeds the costs and the IVS is efficient; if $BCR \geq 3$ holds the BCR is labelled as "excellent".

In a sensitivity analyses, the depending of the BCR results on variables such as penetration rates, system costs, safety effects etc. can be shown.

7 Restrictions of the method

7.1 Limitations

A problem of the method is that not for all benefits and costs of the IVS a quantification and a converting of the impacts into monetary values is possible. In consequence some impacts of an IVS for example by an improved driving comfort are not taken into account if no measurement instrument is available to transfer this impact into a monetary value. Also, if the objective approach of assessment is applied, human costs like pain, grief and suffering are not covered since no well accepted valuation method for these costs exists.

In general, a CBA does not take into account how benefits and costs of IVS are distributed into the society. Thus, although an IVS is considered as efficient from the point of view of the society, it may not be welfare increasing for all relevant groups. This can be an impediment for market introduction of IVS.

7.2 Scalability; extension to real world

The accident and traffic databases in the CBA are used to upscale safety impacts and traffic flow effects to the country-level. Often also upscaling to the EU level is necessary to show the efficiency of IVS on the EU level. However, upscaling to the EU level is sometimes difficult because on the country-level in-depth data about accident types and relevant environmental conditions are not always available in equal quality and reliability to show safety effects of IVS.

7.3 Reliability and risks

The costs and benefits are expected outcomes based on forecasts. With respect to IVS, the market penetration rates in the future could be lower than expected because e.g. of shortcomings of and /or reluctance against the technology such that the safety effects diminish. Also estimations of development of vehicle fleet and vehicle kilometres will be influenced by a change for example in fuel prices. Benefit-cost ratios are therefore estimations under uncertainty. To cope with these risks, minimum and maximum values of costs and benefits can be calculated by developing optimistic and pessimistic scenarios. This may highlight the fact that economic analysis cannot provide exact estimates but rather probable intervals. Also a sensitivity analysis which discusses the reaction of the benefit-cost ratios to critical values of assessment can reduce the uncertainties about the results.

8 Examples of use

- SEISS, "Socio-economic impact assessment of stand-alone and co-operative intelligent vehicle safety systems (IVSS) in Europe", 2005, http://ec.europa.eu/information_society/activities/esafety/doc/call_4/final_seiss.pdf
The SEISS study was funded by EC DG Information Society and Media (Running time: 6 months). The goal was 1) developing a comprehensive methodology for the assessment of the potential impact of the introduction of intelligent vehicle safety systems and 2) to offer case studies in order to demonstrate the workability of the general approach. In the case studies considered IVS are the following systems: eCall, safe following – ACC, Lane departure Warning and Lane Change Assistance.
- CODIA Final study report, Deliverable 5, 2008
The CODIA study was funded by the EC DG Information Society and Media (The Seventh Framework Programme) The goal was the assessment of direct and indirect impacts, costs and benefits of five co-operative systems (Running: 2008). Considered IVS were: Speed adaptation, Reversible lanes due to traffic flow (V2I and I2V), Local danger / hazard warning (V2V), Post crash warning (V2V) and Cooperative intersection collision warning (V2V and V2I)
- eIMPACT, "Socio-economic Impact Assessment of stand-alone and co-operative intelligent vehicle safety systems (IVSS) in Europe", Deliverable 6, 2008, <http://www.eimpact.info/results.html>
eIMPACT was an European Specific Targeted Project co-funded by the EC Information Society and Media. The focus of the project is on socio-economic impact assessment of stand-alone and co-operative intelligent vehicle safety systems (IVSS) in Europe.

Socio-economy

4.13. Multi criteria analysis (MCA)

1 Short description of the method

Multi criteria analysis

As a method for socio-economic evaluation, multi criteria analysis (MCA) is used to measure the performance of an IVS against established criteria. The criteria of the MCA are built on the objectives of the decision making group. This group can consist of experts and relevant stakeholders in the field of IVS. Examples of evaluation criteria are driver safety and comfort, third-party safety, environmental impact and travel time reductions. The experts value the different alternatives against the criteria by given scores for goal achievement.

The analytical hierarchy process (AHP) is probably the most widely used MCA method in decision-making. It provides an explicit relative weighting system for the selected criteria. Given the weights of the various criteria, the analysis permits to measure each systems overall level of goal-achievement such that a complete ranking of the considered IVS results.

2 Context of the evaluation

2.1 Phase – lifecycle of the product / Intelligent Vehicle system

Because the Information requirements for MCA are relatively less demanding compared to cost-benefit analysis, the MCA is applicable especially for the plan/ prototype phase of system development.

2.2 Expected outcome, research questions

Results of MCA inform decision makers about the ranking of the IVS given a set of limited criteria. However, the ranking is only ordinal, i.e. from the values no information about how much one alternative is preferred against a different alternative can be generated. The results could be used as a first indication about the relative performance of an IVS and thus can provide some help to plan further research steps about functions, use cases and potential impacts of IVS.

2.3 Target group of the outcome (public authorities, manufacturers etc.)

An assessment by MCA can provide manufactures / suppliers some information about how to select the most suitable IVS for development e.g. of a prototype or pilot. Such information can also be of some interest for public authorities when they decide about how to distribute public funds on research development expenses for different alternatives of IVS. Consumers usually will not have the data to apply the methods for their choice of an IVS in a vehicle.

2.4 Resources needed

2.4.1 Organisational

MCA does not require special organisational resources.

2.4.2 Personnel

Some experience in empirical research and impact analysis is needed for developing goals, criteria and scenarios for the MCA method.

2.4.3 Technical

Beside software tools for data analyses and calculations (e.g. excel, SPSS) no special tools or software packages are needed.

2.4.4 Financial

Beside financial outlays for required manpower no investments are necessary.

3 Orientation of the method

3.1 Theoretical / empirical; Ex-ante / ex-post

In principal, the scoring against the criteria represents estimations of experts about the performance of IVS according to defined criteria. In addition, the estimations can be based on (theoretical) desk top research, and do not demand empirical research. The assessment can be applied to the past or future performance of IVS.

3.2 Experimental / natural

Not relevant because the method is mainly a decision method.

3.3 Background

The method is a theoretical concept generating an assessment which is valid only for the given objectives of the experts and stakeholders who participate in the assessment.

4 Focus (choose the relevant ones and utilize the criteria from expert enquiry)

4.1 driver behaviour
not relevant

4.2 traffic flow and efficiency
not relevant

4.3 Traffic safety
not relevant

4.4 Environment
not relevant

5 Description of the method

5.1 Short description of the underlying principles

The process of subjective valuation allows integrating impacts of an IVS which cannot be quantified or valued in monetary values in an assessment (e.g. comfort benefits) by using scores. Thus by using the AHP-method, a

complete aggregation of valuation results will be obtained. However, by aggregation, compensatory effects are possible, such that low scores of a criterion could become more important if the weight for this criterion is higher than the weight of a criterion which has a higher score. This means that by weighting and aggregating of single valuations, detailed and often important information can be lost.

5.2 Type of assessment (desktop, lab, simulator, field, statistics)

The MCA approach will be based on an experts' survey, for example during a workshop. Also data from a desktop study can be used as input.

5.3 Process/design

5.3.1 Test persons

The method does not require test persons, but experts' estimations about performance of IVS with respect to selected criteria.

5.3.2 Sample size

If the MCA is based on a survey, the validity of the results depends on the number of experts in the sample. Standard statistical methods can then be used to state the significance of the results.

5.3.3 Set-up, design

The MCA is based on a hierarchy of objectives and subobjectives. This hierarchy can be constructed top-down or bottom-up. Often, a combination of both is applied. The top-down method starts at the top at the fundamental objectives and proceeds downwards until all criteria are included (if possible measured by operational criteria). On the contrary, the bottom-up approach will generate a large unstructured list of criteria, which can be clustered into groups of common elements (subobjectives), leading to potentially the same hierarchy as the top-down approach.

The top-down approach is preferable for dealing with strategic decisions, when the suitable alternatives have not been identified yet. The bottom-up approach works better in situations when the set of alternatives is fixed, and the decision problem is to select a single alternative among them.

The next step of a MCA consists of setting priorities among the criteria such that a weight is given to each criterion. If the number of criteria is relatively large, the method of pairwise comparisons can be used to get a consistent weighting.

Finally, a scoring is done by using a scale, for example a 9-point scale or a 100-point scale. The former scale is easier to apply but reduces the ability to show accurately the differences in goal attainment of the different alternatives.³

³ For more information about the theoretical foundations of MCA see for example the ADVISORS study (Integrated Multicriteria Analysis for Advanced Driver Assistance Systems, Deliverable 6.1, 2000), and the SEISS study (ABELE, J. et al., Exploratory Study on the potential socio-economic impact of the introduction of Intelligent Safety Systems in Road Vehicles, 2005).

5.3.4 Measuring or technical equipment

Beside software tools for data analyses and calculations (e.g. excel, SPSS) no special tools or software packages are needed.

5.3.5 Data requirements

As input to an MCA, experts' surveys or desktop results can be used.

5.4 Expertise needed

Some experience in empirical research and impact analysis is needed for developing goals, criteria and scenarios for the MCA method. Thus expertise will be necessary for developing a questionnaire and preparing and conducting an expert survey for getting weights and votes for the evaluation of IVS.

6 Results

6.1 Type of output

After giving weights to various criteria, the analysis permits to measure each system overall level of goal achievement by scoring and thus identifying the most preferred alternative and providing a ranking of all considered alternatives of the IVS.

6.2 Parameters / description

The parameters of the evaluation are weights and scores. To each criterion of an alternative, a weight is assigned to express how favoured the criterion is. By scoring the expected consequences, each option has to be assigned to a numerical score. The numerical score reflects the strength of preference for each alternative for each criterion. The result is that more preferred options have a higher score on the scale than less preferred options. A usual scale is from 0 to 100. With 0 as least preferred option and 100 as most preferred option.

7 Restrictions of the method

7.1 Limitations

The main limitation of the MCA method is that the generated results hold only for the group of experts who were undertaking the assessment. A generalisation of the results is difficult since a different group of experts will use different evaluation criteria. In addition, the scoring of the alternatives is subjective, but of course based on the scientific expertise of the experts.

The main limitation of the MCA method is that it depends on the expertise and judgements of who were undertaking the assessment. A generalisation of the results is difficult since a different group of experts will use different evaluation criteria. The scoring of the alternatives also, in principle, is subjective, but, of course based on the expertise of the experts

A further problem of the method is the rank reversal problem. This means that, in some cases, the ranking of the alternatives can be reversed when a new alternative is introduced. In the AHP method, rank reversal is likely to occur e.g. when a copy or a near copy of an existing alternative is added to the set of alternatives that are being evaluated.

7.2 Scalability; extension to real world

Because the ranking of the alternatives is based on subjective estimations of an experts' survey and since the assessment holds only given the set of alternatives and criteria, a generalisation of the ranking is normally not possible. A minimal requirement for a careful generalisation would be that the sample of experts represents the scientific state of the art according to the scientific community to which they belong. If this is the case, 10 to 20 experts can be enough to get meaningful results.

7.3 Reliability and risks

Because of the subjectivity of the assessment and the Rank-reversal problem, the risks of using the method for decision making is relatively high. Therefore an extensive sensitivity analysis of these evaluations should be performed in order to investigate whether the ranking of the IVS would change when other sets of weights would be used to get some hints about stability of the results.

8 Examples of use

- ADVISORS, Action for Advanced Drivers Assistance and Vehicle Control System Implementation, Standardisation, Optimum Use of the Road Network and Safety

The ADVISORS study was funded by the 5th Framework within the European Competitive and Sustainable Growth Program (running: 4/2001 – 12/2003). Its goal was to develop a methodology to assess the impact of different types and different levels of penetration of advanced driver assistant systems (ADAS).

The method was applied in the project with the members of the ADVISORS consortium and members of the Belgian Institute for Road Safety. Defined criteria were driver safety and comfort, traffic flow efficiency, acceptance, technical feasibility, driver costs and environmental performance of the road transport system.

- eIMPACT, Socio-economic Impact Assessment of stand-alone and co-operative intelligent vehicle safety systems (IVSS) in Europe, Deliverable 7, 2008, <http://www.eimpact.info/results.html>

eIMPACT was an European Specific Targeted Project co-funded by the EC Information Society and Media. The focus of the project is on socio-economic Impact Assessment of stand-alone and co-operative intelligent vehicle safety systems (IVSS) in Europe.

The goal of the deliverable was to describe key elements for feasible policy options to promote the market introduction and penetration of IVSS (e.g. awareness campaigns, driver education, system as standard equipment instead of optional, insurance premium reduction). In a stakeholder workshop the policy options for market deployment were ranked according to the perceived suitability of each policy option and given the weighted evaluation criteria.

5. Conclusions

This document presents the catalogue of impact assessment methods for intelligent vehicle systems (IVS). It is directed to anyone who is responsible for the impact assessment of IVS or uses the results of the assessment of IVS, such as decision makers, developers and researchers.

The report is a draft version towards a more comprehensive catalogue of impact assessment methods. The purpose of this draft is to act as a basis and catalyst to the discussion on the use, requirements and detailed contents of such a catalogue.

The methods were identified and described based on the sample of studies listed and shortly described in the iCars deliverable D3.1 and D3.2. The impact assessment criteria were developed in these earlier phases and complemented in this report.

The catalogue includes methods for various uses with regard to impact areas, assessment type as well as the phase in the life-cycle of the system assessed. In all, eleven methods are described in this catalogue. Four methods to study behavioural effects were included, two for safety, two for environment, one for efficiency, one for mobility and two for socio-economic impact assessment.

Safety impact assessment methods dominate the material. In addition to the two directly traffic safety focused methods, the four methods on behavioural changes focus on traffic safety. Traffic safety goals have dominated the impact assessments because the societal impacts for safety, also indicated in monetary values, are considerable.

However, the methods as such or slightly modified could be utilized for other purposes as well. The global goal to reduce CO₂ emissions calls for new applications and impact assessment methods for the environmental impacts. Until now, the weight of environmental impacts has been quite small in the socio-economical calculations. In the future the importance to assess the environmental impacts may be more important.

Mobility impact assessment of ITS systems seems to be a new area, and not too many methods were identified. It is assumed that the demand of mobility impact assessment is increasing in the future, based on the of ITS applications' ability to affect mobility.

Figure 3 relates the methods to the impact areas and the phase in the life cycle of the system. As shown in this figure, all phases in the life cycle have been covered by the methods. Concerning the impact areas, all areas were covered as well. Most methods can be used for more than one impact area, as was shown in Table 1.

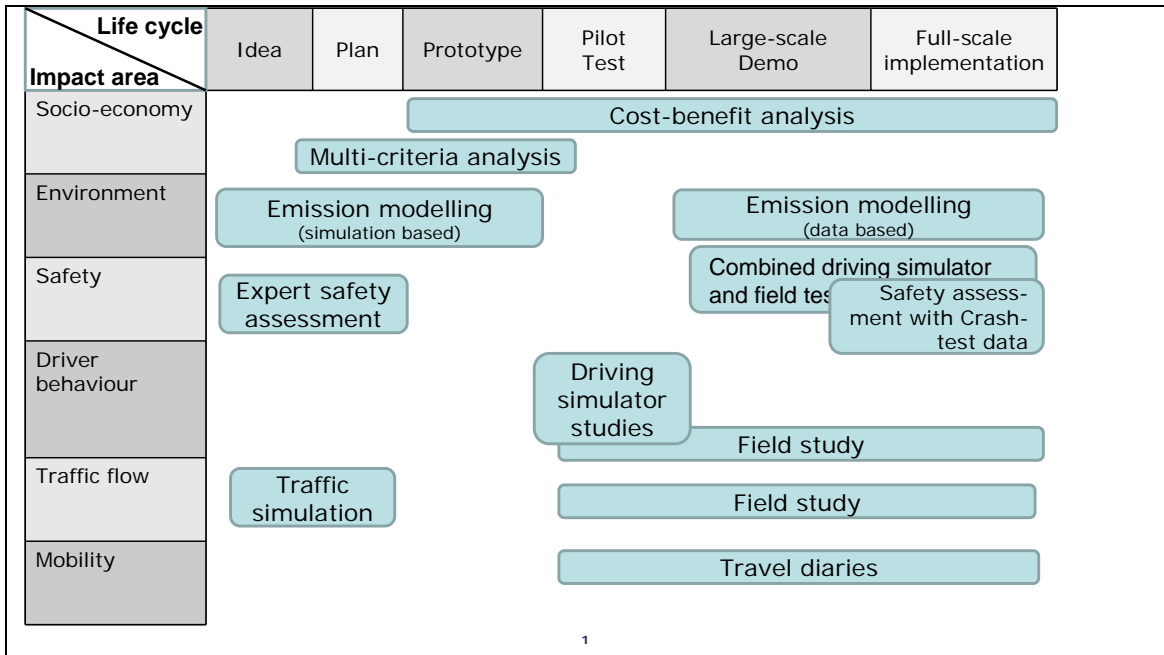


Figure 3. Relation of methods to impacts areas and development phase.

The purpose of the document is not only to list different methods, but also to characterize a method's application area and the method, including its limitations, by suggesting appropriate assessment criteria and then assessing the methods. The concept of 'method' is elaborated in the form of a framework as presented in the appendix. This framework includes (among others) a description of the method, context of the evaluation, the expected outcome, target group of the outcome, resources needed, process/design, type of output and parameters, restrictions of the method, scalability and extension to real world, reliability and risks and examples of use.

The authors are aware that the presentation of the methods without any practical, financial or other real context is theoretical. The issue was discussed on some level in the method descriptions.

The selection of a method for an impact assessment study of an IVS is always related to a research question, either implicitly or explicitly expressed, which is covered by one of the defined impact areas. For example, if the research question is how drivers will use a new IVS, this is contained in the impact area Driver behaviour, and a Driving simulator could be an appropriate method.

Also, the choice of a method depends on how far the IVS is developed (the phase in the life cycle) and the available finances. In Table 3 the investigated methods are shown in relation to these two factors. It however has to be noted that the cost indication is only a rough estimation and depends on many factors.

Table 3: Methods classified to costs and development phase

		Development phase					
		Idea	Plan	Prototype	Pilot test	Large-scale demos	Full-scale implementation
Costs	low cost	Expert assessment on safety impacts Multi criteria analysis (MCA) Traffic simulation	Expert assessment on safety impacts Multi criteria analysis (MCA) Traffic simulation	Expert assessment on safety impacts Multi criteria analysis (MCA) Focus group study Traffic simulation	Expert assessment on safety impacts Cost benefit analysis (CBA) Focus group study Traffic simulation	Expert assessment on safety impacts Cost benefit analysis (CBA) Focus group study Travel diaries	Expert assessment on safety impacts Safety assessment with Crash Data Cost benefit analysis (CBA) Focus group study Travel diaries
	medium cost	Emission modelling Driving simulator studies	Emission modelling Driving simulator studies	Emission modelling Driving simulator studies Small-scale field test with instrumented vehicles	Combined driving simulator and field test Small-scale field test with instrumented vehicles Air quality monitoring	Combined driving simulator and field test Air quality monitoring	Combined driving simulator and field test Air quality monitoring
	high cost					Large-scale field study	Large-scale field study

The methods can be applied in a more or less successive manner depending on the resources available. Furthermore, a closer look to the methods reveals that in some cases they overlap – especially, a field study may include several sub-methods and measurements. The methods have varying levels of details, and there might also be effective combinations of methods as combined driving simulator and field test.

In the continuation of the iCars Network project, the impact assessment catalogue will be elaborated further. A workshop will be organized with external experts and potential users of the catalogue. The current version is already reviewed shortly by some external experts. The general impression of them was that this catalogue is useful for them, because it gives an overview of a wide range of methods, while most researchers are specialists in one method / impact area and an overview about available methods is often missing.

APPENDIX 1: Framework for method description

- 1 Short description of the method
- 2 Context of the evaluation
 - 2.1 Phase – lifecycle of the product / Intelligent Vehicle system
 - 2.2 Expected outcome, research questions
 - 2.3 Target group of the outcome (public authorities, manufacturers etc.)
 - 2.4 Resources needed
 - 2.4.1 Organisational
 - 2.4.2 Personnel
 - 2.4.3 Technical
 - 2.4.4 Financial
- 3 Orientation of the method
 - 3.1 Theoretical / empirical; Ex-ante / ex-post
 - 3.2 Experimental / natural
 - 3.3 Background
- 4 Focus (choose the relevant ones)
 - 4.1 driver behaviour
 - 4.2 travel behaviour
 - 4.3 traffic flow
 - 4.4 efficiency
 - 4.5 safety
 - 4.6 environment
 - 4.7 mobility
 - 4.8 socio-economy
- 5 Description of the method
 - 5.1 Type of assessment (desktop, lab, simulator, field, statistics)
 - 5.2 Process/design
 - 5.2.1 Test persons
 - 5.2.2 Sample size
 - 5.2.3 Set-up, design
 - 5.2.4 Measuring equipment
 - 5.2.5 Data requirements
 - 5.3 Expertise needed
- 6 Results:
 - 6.1 Parameters / description
 - 6.2 Type of output
- 7 Restrictions of the method
 - 7.1 Limitations
 - 7.2 Scalability; extension to real world
 - 7.3 Reliability and risks
- 8 Examples of use
 - 8.1 Authors / Developers, key references to the method and its application to ITS
 - 8.2 Availability of an electronic version