STANDARDISATION, IMPLEMENTATION AND OPTIMUM USE OF ADVANCED DRIVER ASSISTANCE AND VEHICLE CONTROL SYSTEMS

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Abstract: Today, intelligent transport systems, especially systems that may assist the driver like Advanced Driver Assistance Systems (ADAS), present a high potential for the improvement of road safety and traffic capacity, as well as for the attenuation of traffic related environmental load. The EC co-funded ADVISORS research project dealt with the development of a comprehensive framework for the analysis, assessment and prediction of the implications of a range of ADAS, as well as with the development of implementation strategies for ADAS, which are expected to have a large positive impact on safety, traffic capacity and the environment. On this purpose, an integrated methodology, called Common Assessment Methodology (CAM) was developed and implemented. The main steps of this Common Assessment Methodology concerned identification of ADAS for evaluation; risk analysis; actor/stakeholder analysis; identification of criteria and appropriate weights; "operationalisation" by identifying specific indicators; overall analysis; ranking; and development of implementation strategies. In this paper, the Common Assessment Methodology is presented, its application within the ADVISORS project is demonstrated and the main findings are outlined, leading to useful input for the further development and implementation of Advanced Driver Assistance Systems.

Keywords: Advanced driver assistance systems (ADAS), Vehicle Control Systems.

1. INTRODUCTION

In accidents in the European Community around 40.000 people are killed every year, the economical costs as a result of congestion are huge, and there is a strong motivation in trying to reduce the emissions of various pollutants, as defined in the Kyoto agreement.
Among other solutions, intelligent transport systems, especially systems that may assist the driver like Advanced Driver Assistance Systems (ADAS), present a high potential for the improvement of road safety and traffic capacity, as well as for the attenuation of traffic related environmental load. Within this perspective, car manufacturers are developing many of these systems, which will eventually enter the market in the coming years. Consequently, Advanced Driver Assistance Systems constitute a great future challenge for both road traffic and vehicle industry and the results of the EC co-funded project ADVISORS, which dealt with several ADAS related parameters, could be proved very useful within this perspective.
Within this paper the overall results of the ADVISORS research project are presented. More precisely, the ADVISORS project dealt with the development of a comprehensive framework for the analysis, assessment and prediction of the implications of a range of ADAS, as well as with the development of implementation strategies for ADAS, which are expected to have a large positive impact on safety, traffic capacity and the environment. The ADVISORS project was a joint initiative of 14 Organisations under the European Union's fifth Framework Research and Technological Development Programme, aiming to contribute to the improvement of road traffic safety, an efficient utilisation of the available road network, and a minimised environmental loading in Europe. The proposed means are guiding and recommending assessment methods and tools, as well as implementation strategies for different types of ADAS.

1.1 Objectives

The basic project objectives include (ADVISORS, 1999):

- Identification of a set of ADAS with high potential to overcome important safety hazards, road capacity bottlenecks, driver behaviour problems and environmental load in several road types.
- Identification of the major legal, institutional, socio-economic, financial, organisational and user acceptance barriers to the implementation of such systems embedded in a decision framework and measures and strategies to overcome them.
- Development of an integrated assessment methodology and relevant criteria to reliably assess traffic safety, usability, interaction safety, user acceptance, road network efficiency and environmental impacts of ADAS.
- Assessment of the impact of emerging longitudinal, lateral and combined ADAS on road safety, driver comfort, as well as on the overall road network efficiency and the environment, using the above methodology, through multipurpose Pilots.
- Development of recommendations for type approval, a common legal framework and standards in the area of advanced driver assistance systems, as well as proposal of funding and incentive mechanisms for their social optimum deployment.
- Promotion of user and stakeholder awareness of such aids and through it enhancement of societal acceptance of them.
- Help realise exploitable ADA systems.

1.2 Common Assessment Methodology

To achieve the above objectives, a complex methodology, called Common Assessment Methodology (CAM) was developed and implemented. This methodology constituted the core of the project approach, in which the development of the methodological framework has taken place. The methodological framework is to be understood as an approach in defining the considerations for decision-making concerning the procedure of choosing ADAS, defining indicators and criteria for assessment of relevant impacts and defining implementation strategies. The common assessment methodology is illustrated in Figure 1 and explained here-after.

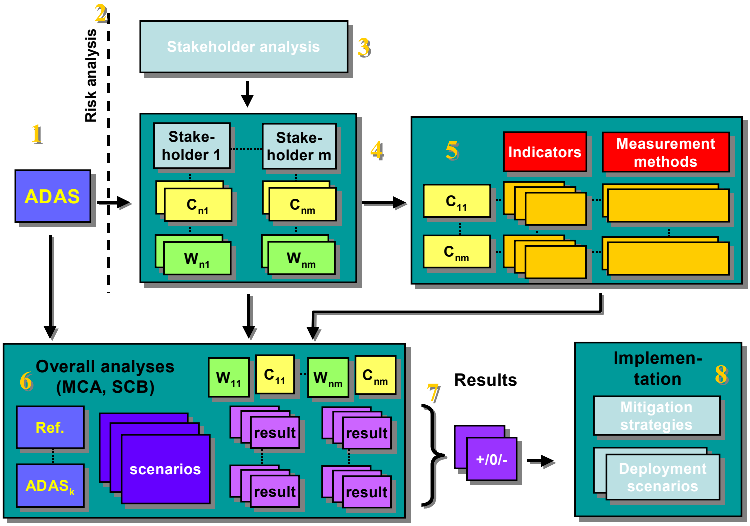


Figure 1. Common Assessment Methodology

Figure 1 explains the methodology developed for the assessment of ADAS effects, prioritization and devising implementation strategies. The main steps of this Common Assessment Methodology (the numbering corresponds to the representation in Figure 1) are:

1. **Identification of ADAS** for evaluation. Classification involves labeling of ADAS function (according to commonly agreed terminology), defining technical capabilities and scope, and considering the scenarios where the ADAS will be used.
2. **Risk Analysis** concerns an assessment of the risks concerning the impact of ADAS market penetration and successful implementation of the ADAS, previously identified.
3. Actor/**stakeholder analysis**: it is essential to provide a sound understanding of the needs and requirements of the different stakeholders (actors) involved with the deployment of ADAS, in order to assess the playing fields for ADAS deployment.
4. **Criteria and weights**. Following the identification of stakeholders and their goals, the next stage is to identify the costs and benefits that a system may give to each stakeholder group and the costs and benefits associated with its use. The appropriate assessment criteria can then be identified.
5. The previously identified stakeholder criteria need to be **"operationalised" by identifying specific indicators** (also called metrics or variables) that can be used to measure whether, and to what extent, a specific criterion is achieved. The indicators are generated by measurement methods and are specified in detail.
6. **Overall analysis** (Multi Criteria Analysis (MCA) methodology) of various ADAS scenarios evaluated through pilot tests, traffic simulation, and expert assessment, using the criteria and weights, and specific indicators identified in the previous steps.
7. **Ranking.** Results of the MCA relate towards the decision with regard to ADAS implementation on the basis of future scenario ratings.
8. Finally, a set of **implementation strategies** are developed and presented in the following stages of development: Choice of future implementation scenarios, Consideration of barriers and risks, Design of Implementation Strategies, and Strategy validation.

In the following sections, all steps of the Common Assessment Methodology are presented, accompanied with the major findings. In the last section the most important overall conclusions and recommendations are presented. A complete presentation of the project findings can be found in ADVISORS (2003).

2. IDENTIFICATION OF ADAS

The state-of-the-art gives a broad overview of ADA systems under development or in some cases already available. It is envisaged that in the near future ADA systems - until now mostly separate systems - will be integrated into one overall system. From a safety point of view, the following systems have a great potential to prevent accidents:

- Systems that enhance the perception of the traffic environment and so enhance situation awareness in the driver
- Systems that assist specific manoeuvres like overtake checker or obstacle/pedestrian detection
- Systems that avoid impending collisions e.g. lateral collision avoidance or rear-end collision avoidance
- Speed control systems that adjust the maximum speed to traffic- and roadway conditions

These systems satisfy important needs the driver has when carrying out the driving task on manoeuvre- and operational level.

Systems that are made to increase driver comfort such as navigation systems will have little or indirect effect on safety, but those systems are expected to reduce environmental load and congestion somewhat due to a reduction in superfluous driving. Moreover, these systems, together with speed control, have the potential to cooperate with infrastructure-bound traffic management systems.

The effect on safety of the above mentioned safety systems will also depend on the penetration rate. The effect on safety may even be negative when only a small part of the vehicles is installed with ADAS, because of unpredictable behaviour for other drivers, unless the ADA system behaves like a human driver ("a Turing machine"). So it may be expected that the effects will change in the course of time when more and more road users get to know and expect the particular ADAS behaviour.

The user needs will also change with the introduction of ADA systems. As the driver receives more information in the car than before, the human machine interface is of fundamental importance, to prevent misunderstanding between human and machine and vice-versa. An automatic test system should therefore be part of the ADA system, to inform the driver when the system is not functioning (properly).

Figure 2. ADAS extended shortlist for further analyses

Finally, a shortlist of Advanced Driver Assistance Systems was selected for further examination (Figure 2). In this Figure 2, only those systems are listed, for which there is reasonable data availability allowing the organization of pilots or the execution of further research. (ISA stand for Intelligent Speed Adaptation and ACC for Advanced Cruise Control). Several criteria were considered for the shortlisting of ADAS. A basic dimension was that ADAS should not hamper the processes in which human drivers are naturally good at. Systems that appear to decrease the driver's ability in understanding and predicting traffic situations should not be pursued.

3. RISK ANALYSIS

Risk Analysis concerns an assessment of the risks concerning the impact of ADAS market penetration and successful implementation of the ADAS, previously identified. The approach is based on Failure Mode and Effects Analysis (FMEA) methodology (Breyfogle, 1999). The relevant indicators of *severity, occurrence probability, delectability* and *recoverability* are expanded to cover not only technical risk but also *behavioural, legal and organisational – related* risks. This methodology is really innovative, as FMEA so far has been used strictly for technical risk assessment.

FMEA aims to determine the relationship between failures, malfunctions, operational constrains, and degradation of performance. It determines the effect of each failure on the system and those failures critical to system success or personal safety, called *single failure points*. It also ranks each failure according to the criticality of the consequences and the probability of occurrence. This procedure is the result of two steps; Failure mode effect analysis and critical analysis (together abbreviated as FMECA).

Table 1 lists the main steps in the FMECA methodology along with a brief explanation. A detailed explanation of the methodology is outside of the scope of this paper.

Table 1. FMECA steps and their explanation

FMECA steps	***Explanation***
System definition	Definition of its functional, environmental and regulatory requirements. This includes the systems' primary and secondary functions, system constraints, acceptable and unacceptable performance, etc.
Development of block diagrams	The diagrams should show relationships of the different elements and the interdependencies between them. More than one diagram may be needed to show the different modes of operations. A task analysis or fault tree analysis may be used for this.
Failure modes, causes and effects	Identification of failure modes, their cause and effects, their importance and their sequence. This identification can be enhanced by the use of a list of failure modes. The failure effects identified at the lower level, may become failure modes at a higher level.
Design alternatives	Identification and evaluation of design alternatives like elements that allow continued operation when one or more functions fail, or the identification of alarm devices.
Criticality of failure mode	It may be relevant to quantify the criticality of a failure effect. This can be done by defining a list of critical failures for each item of equipment, based on their consequences.

Probability of failure mode	Probability of occurrence can be estimated using reliability databases and is expressed in for example p = 0.005, which means that the failure occurs 5 times out of one thousand. Another option is to rate probability according to the following levels: Frequent, Probable, Occasional, Remote, Unlikely.
Criticality evaluation	The evaluation of criticality may be undertaken using a criticality grid. It must be noted that in many circumstances the probability or criticality scale is non-linear.

4. STAKEHOLDER ANALYSIS

The general idea of the stakeholder approach can be summarized as indicated in Figure 3. Three stakeholder groups can be distinguished, who each develop their own criteria for the evaluation of the ADAS, namely the users, the producers and society as a whole. Each stakeholder in fact performs an evaluation of the ADAS in terms of her own objectives. Since not all criteria are equally important to the stakeholders, the stakeholders therefore use weights, which together with the different ADAS and the criteria developed by them are used as inputs to their own Multi-Criteria Analysis (MCA) (Saaty, 1995). This means that three different MCAs are performed, which each have a limited focus, namely a stakeholder-specific focus. The users are concerned by the full user cost, driver comfort, driver safety and travel time duration. Society is concerned with public expenditure associated with ADAS introduction, the environmental effects (impacts on emissions, noise, etc.), overall safety, full social implementation cost (incl. e.g. subsidies), network efficiency and acceptability. Finally, the producers are interested in innovation cost, sales volume, internal spill-over effects, profitability and company status. In the second phase, an overall socio-economic MCA evaluation is to be performed. This is an overall MCA, which integrates all points of view and encompasses all stakeholders. The result of this analysis is subject to sensitivity analysis.

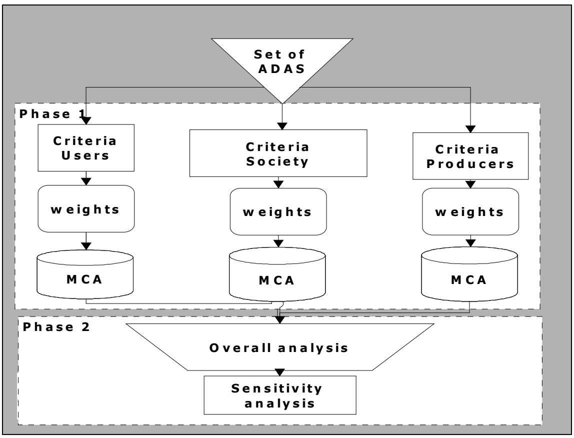


Figure 3. Overview of the stakeholder approach.

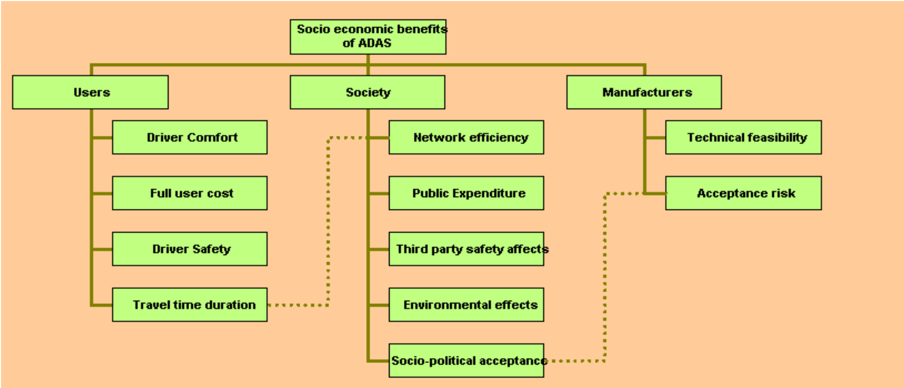


Figure 4. Decision tree for the evaluation of ADAS.

The decision tree developed (Figure 4) was the result of initial development and refinement: operational criteria were developed which make it possible to measure the impacts of each separate ADAS on these criteria. represents the hierarchical decision tree and also shows the linkages between the criteria (dotted line). For example, there is a link between the effect of ADAS on network efficiency and user travel time. Similarly, the manufacturers and society at large share a similar interest, namely the risk of low societal acceptance. In order to avoid double counting, these criteria were represented only once in the final evaluation table and placed under the heading of the stakeholder group that would likely attach the greatest importance to them.

5. DETERMINATION OF CRITERIA AND WEIGHTS

The weights were determined by expert evaluations. The relative "priority" given to each element in the hierarchy was determined by comparing pair-wise the contribution of each element at a lower level in terms of the criteria (or elements), with which a causal relationship exists. In the resulting list driver safety and third party safety effect received the highest weights.

A second group of criteria with still relatively high weights consists of travel time reduction/network efficiency and the environmental effects, i.e., two key mobility problems. Technical feasibility, the full user cost and the socio/political acceptance, received more moderate weights. Finally, the last group includes criteria viewed as somewhat less important, such as public expenditures and driver comfort.

6. OPERATIONALISATION THROUGH INDICATORS AND MEASUREMENT METHODS

In this step, the previously identified stakeholder criteria were "operationalised" by constructing indicators (also called metrics or variables) that can be used to measure whether, or to what extent, an ADAS contributes to each individual criterion. Indicators provide a "scale" against which a project's contribution to the criteria can be judged. Indicators are usually, but not always, quantitative in nature. More than one indicator may be required to

measure a project's contribution to a criterion and indicators themselves may measure contributions to multiple criteria.
Assessment parameters are those parameters that define the independent variables and the manipulations of the ADAS tests. The scenario used when assessing an ADAS determines the assessment parameters. The scenario is a key methodology issue as the prevailing conditions outside (and inside) the vehicle strongly influence the outcome of the assessment and the conclusions that can be drawn. Scenario specification and assessment parameter definitions have to be included when assessment methodologies are developed.
The assessment parameters, defined by the scenario, and identified as necessary to consider for ADAS assessment include:

- Driver
  - Participants (age, experience, gender, special characteristics)
- Vehicle and ADAS System
  - Vehicle type
  - Level of automation
- Road and Traffic
  - Road type (rural, urban, motorway)
  - Traffic conditions (light, medium, heavy)
- Environmental issues
  - Road surface (damp, wet, dry)
  - Weather (dry, fog, rain, snow)
  - Lighting (normal, glare, dark/unlit)

The ADAS can be seen either as a component that stands for itself or as being part of the vehicle component. One way of illustrating the scenario concept is shown in Figure 5. It is important to note that the significance of the different scenario components may vary in different assessments. Also, the components are related to each other and interact in different ways in different cases.

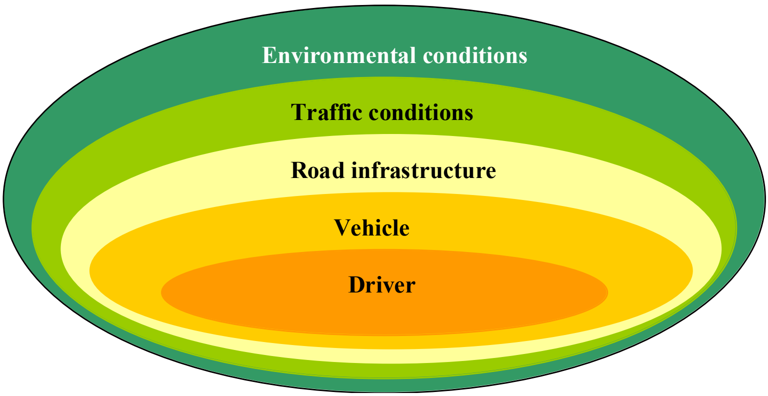


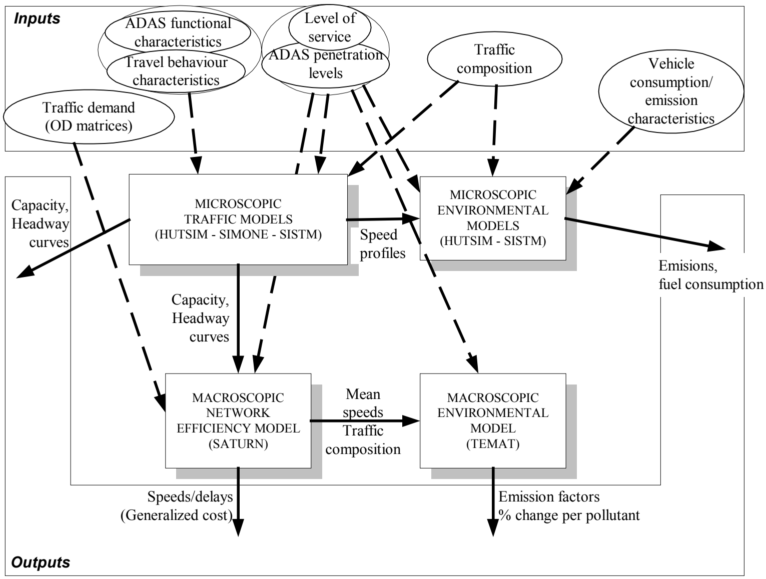
Figure 5. Main components to be considered and specified when building assessment scenarios.

The evaluation types identified as relevant for ADAS assessment are pilot tests (in simulator, test track, or real traffic) and traffic modeling, (using both microscopic and macroscopic simulations). An overview of the methodology and results of these evaluations follows.

Indicators are used to assess traffic safety, user perspective (e.g. usability (Brooke, 1996) and driver comfort), Human-Machine Interface (HMI) factors and interaction safety, and road network efficient, traffic safety and environmental impact. For example, indicators relevant to traffic safety include driver measures (errors, workload, stress, fatigue, situation awareness) [Brookhuis and Waard (2001), Brown (1997)], as well as vehicle measures (longitudinal and lateral vehicle control, time headway, time to collision, speed).

6.1 Simulation methodology and results

Detailed existing models examine the impact of ADAS at the microscopic level (Kosonen (1999), Minderhoud and Bovy (1999), and Stevens et al (2000)). Their findings are used as input for a set of macroscopic models (MEET (1999), van Vliet and Hall (2002)) in order to examine the ADAS impact on a network level. Necessary inputs to the methodology include system penetration level, the demand level of the network elements, the various modelled ADA systems' functional characteristics, the driver behaviour parameters, the traffic demand and composition and the vehicle consumption/emission characteristics.
A *microscopic* traffic model produces a set of outputs, including capacity information and headway curves, which are used by the macroscopic traffic model, and speed profiles that are used by the environmental models. A microscopic environmental model calculates emissions and fuel consumption per vehicle. A macroscopic traffic model produces information on average speed for each link and the whole network considered while a macroscopic environmental model calculates emission factors and changes in pollutants per link and on a network basis (Figure 6).



<u>*Figure 6. Overall methodology macroscopic and microscopic simulations*</u>

The sensitivity of the simulated impacts to the prevailing demand level has also been tackled, where it was feasible. This effort concluded that ADAS may have significant impact on traffic, safety and environmental conditions for high system penetration levels and peak period traffic conditions.

6.2 Pilot Tests

The assessment areas that were considered in the pilot tests include task performance, driver performance, driver workload, system usability, driver acceptance, willingness to pay, driver profile and terminology. One of the outputs of the project was a "user-friendly" terminology for ADAS. Indicative basic results obtained from the pilot tests are presented here-after.
The addition of Stop and Go (S&G) functionality to ACC influenced speed differently. Furthermore, ACC increased driving in the left ("fast") lane. Driver workload was generally reduced by ACC and ACC+S&G. While ACC enjoyed high and consistent acceptance, ACC+S&G had low acceptance rates, especially for young drivers. Finally, a good willingness-to-pay a moderate price was observed for ACC, Lateral Support System (LSS), and Driver Monitoring System (DMS) [Fairclough, Brookhuis, Vallet (1993)], while 30-40% will not pay anything for ACC+S&G.

7. OVERALL ANALYSIS AND RANKING

Furthermore, a strategic assessment methodology was developed based on a formal, analytical process that incorporates technical and stakeholder perspectives. The main strength of a multi-criteria, multi-actor approach is that it builds upon the stakeholders' own objectives in establishing evaluation criteria, thereby facilitating the ultimate implementation of specific technologies associated with high net benefits. The methodology has been applied to a number of ADAS that could be commercialized on a large scale within the next decade.
The result of this work may be relevant within the framework of an industrial policy that aims to stimulate the development of strategic new technologies in Europe for which implementation priorities have been determined in this study. The results suggest that the most promising ADAS include the integrated system, the driver monitoring systems, mandatory Intelligent Speed Adaptation [ISA, Oei (1998b)] and Advanced Cruice Control [ACC, Oei (1998a)]. However, the various systems are viewed attractive for different reasons: for example, mandatory ISA provides high societal benefits whereas the ACC system results in lower safety or traffic benefits but is associated with a higher user desirability.

8. IMPLEMENTATION STRATEGIES

Before preparing the scenarios, a scenario definition (scenario template) listing all the key parameters was produced. This ensured that all the prepared scenarios included comparable information in similar parameters. The working method is presented below (Figure 7). The scenarios were made as preliminary most preferred ADAS scenarios. The scenarios are developed further in continuing work in the work-packages on MCA and Implementation strategies.

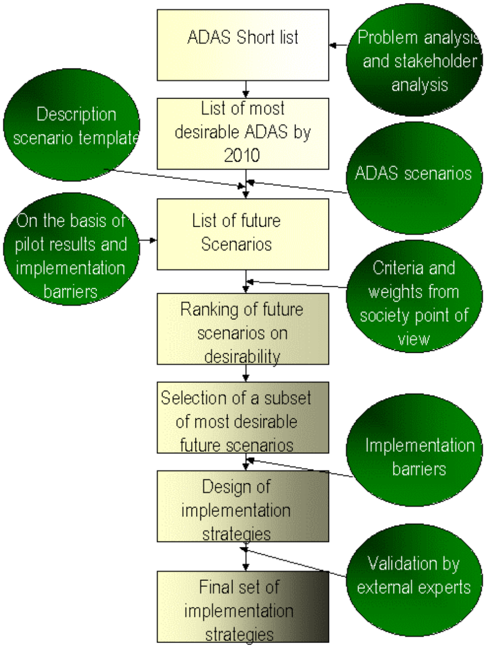


Figure 7. Working method for defining the preliminary most desirable and likely ADAS scenarios.

A scenario was defined to be a *snapshot* view of a possible (usually future) set of circumstances. In this project, scenarios are created so that predictions can be made about the effects of introducing new ADAS in road transport.

However, one needs to keep in mind, that in addition to the listed actions, there are numerous factors directly or indirectly affecting the implementation of new technology. The users' willingness to pay is not the only thing affecting the release of new technologies. There might be bottlenecks in the domain of regulations, insurance or standards or it might be even forbidden to release certain ADA products under the current laws. Also the lack of regulations might cause some limitation to the ADA systems that are introduced to the market - the manufactures can perceive substantial litigation risks due to missing rules, guidelines or definitions of system characteristics. In addition to mentioned factors, also the type of ADA systems (open and closed ADAS and autonomous and dependent ADAS) affects the implementation speed and manufacturers' interest to develop the ADA system.

The Actor Analysis showed that the estimated utilities indicate that the ***navigation*** attribute is most important, which indicates that the availability of navigation support within future ADAS applications can have a considerable effect on preferences for ADAS. As such, the implementation of navigational aids, preferably as part of an integrated system, should be stimulated. ***Price*** is the second important attribute. This implies that financial incentives can improve the preferences for ADAS. This would require, however, some additional research on how respondents expect that ADAS might be implemented. In the study no specifications were given if the ADAS were available for new vehicles only (like current distance keeping) or might be installed in existing vehicles also (like current speed adaptation devices and navigation systems). Purchase prices of vehicle equipment for new vehicles are perceived as

relatively low as compared to the price of the new vehicle itself. These perceptions might have influenced the importance of the attribute price and will be subject of our future research.
With respect to distance keeping and speed adaptation, the ***warning level*** is more preferred than the other levels. These findings suggest that it has to be tried to implement systems that have a warning functionality. In addition, regarding speed adaptation, warning support is preferred to no support. Hence, there appears a need among drivers for speeding warnings. Regarding navigation, the ***dynamic route info level*** is more preferred than the other levels. As such, an effort should be undertaken to (further) implement systems which couple actual traffic information with in-vehicle navigation support.
ISA will be developed step-by-step with increasing functionality. The building of Galileo satellite system will increase the precision of the location of vehicles and will be stimulating for the further improvement of enhanced navigation and ISA.
Although subsystems often are being developed and implemented separately, integration of hard- and software (when possible) is to be expected and also a must. The same applies to the integration of information to be presented to the driver. Standardisation is also needed. The expectation is that in future an integrated system can be reached, after the needed research, testing and evaluation have been conducted. The question is whether a mandatory system such as ISA is needed. This depends among others on the penetration and use of voluntary ISA in practice and the effect on traffic speed.

9. CONCLUSIONS AND RECOMMENDATIONS

The Common Assessment Methodology is an approach for choosing the relevant effects from the use of Advanced Driver Assistance Systems, the assessment of the ADAS effects, the prioritization of implementation aims and the devising of implementation strategies. The approach developed, should be considered as a comprehensive approach covering a wide range of ADAS related aspects. Although the approach is developed in the field of ADAS research, one could imagine that the approach can be transferred to other fields for which new (technological) developments take place. Naturally, some of the ADAS specific elements have to be replaced.
One of the elements of the Common Assessment Methodology is the review and listing of pilot testing methods and the overview of measurement methods. This is a very practical tool for many researchers in the field, or in other fields in which operator behaviour is important. A first set of criteria has been defined for evaluating whether a measurement indicator shows a result that is outside acceptable boundaries or not. However, the problem is usually that the effect of an ADAS gives rise to a pattern of behavioural effects, and that the pattern itself is conclusive. Certainly, more research is needed, and a database of criteria should be developed, as part of a meta-project.
The empirical studies gave rise to many behavioural results; most importantly the direct behaviour of the driver, as well as the problems still involved in the parameters of the ADAS. For instance, the urban ACC system was not very much liked by the drivers. Partly, the setting of the parameters (pre-set speed too high), partly the fact that a system interferes is the cause of the problems. The option of being able to adjust the parameters is to be considered. Both the urban ACC and the interurban ACC reduce driver workload.
The ACC was generally accepted by the drivers, particularly younger drivers; slightly more left-lane driving and smaller time headways were observed; the DMS is certainly worth developing further, especially for professional drivers. The HMI studies revealed that people

do not like warning signals, which represent a "crash" sound, but they do prefer acoustical warning signals only.

The simulation tests, both microscopic and macroscopic are very revealing in their effects on traffic flow and environmental load. For instance, ACC effects for traffic flow increase at higher penetration rates and lower speed. The reduction in emission levels for ACC is higher than for ISA, especially with higher penetration levels. The effect of ISA on traffic capacity is minimal.

The Multi Criteria Analysis revealed a prioritisation of criteria, in which two safety criteria come first, followed -after a large distance- by environmental effects and travel time, then technical feasibility, user costs, socio-political acceptance, driver comfort and public costs.

Integrated ADAS, the Driver Monitoring system for professional drivers, intervening ISA in urban areas and ACC on the motorway with high flow have come out as the most important, high priority ADAS.

The Implementation Strategies reveal that different issues are to be solved for each ADA system. ACC, a system that typically is approaching the market today, bears some safety problems. Implementation strategies have to address these problems. Driver training, standardization are important, inquiring after the options of manual adjustment of the settings. ISA is a growing scenario, in which the functionality and sophistication is gradually increasing over time. The link with the navigation system, especially with the *dynamic* navigation system is of utmost importance. Cooperation between authorities and a commercial partner is important. The Driver monitoring system could be a welcome system to support professional drivers. Still, research and development need to be done to increase the number of people for which the system can be helpful. The Integrated ADAS system is still far away, and safety implications are still very uncertain.

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