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ADVANCED DRIVER ASSISTANCE SYSTEMS: AN OVERVIEW AND ACTOR POSITION

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Abstract: This paper shows some details and acceptability aspects of three types of systems which are part of a comprehensive State of the Art review on Advanced Driver Assistance Systems: Navigation, Advanced Cruise Control & Stop and Go, and Intelligent Speed Adaptation systems. It was concluded that luxury car drivers considered the warning type of Intelligent Speed Adaptation acceptable and expected this to have a positive impact on road safety, and that truck drivers found the navigation functionality most attractive in general, and Advanced Cruise Control & Stop and Go functionality on motorways and rural roads. *Copyright © 2002 IFAC*

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1. INTRODUCTION

Advanced Driver Assistance Systems (ADAS) are expected to increase road safety, road capacity and attenuate environmental load in traffic. Several of these systems will enter the market, some sooner, some later. However, the impacts of these systems may in some cases have beneficial effects, but not in all cases. Furthermore, the current implementation of the new ADAS is mostly based on technological push. The needs and preferences of the end-users have not been studied thoroughly yet. There is also lack of information about users' willingness to accept and pay for the new technology.

The ADVISORS project (**A**ction for advanced **D**river assistance and **V**ehicle control systems **I**mplementation, **S**tandardisation, **O**ptimum use of the **R**oad network and **S**afety), funded by DGTREN of the European Commission, has formulated as its overall objective to develop a comprehensive framework to analyse, assess and predict the implications of a range of ADAS, as well as to develop implementation strategies for ADAS with a high positive expected impact.

In the first stage of the project, a State of the Art of ADAS is produced: an analysis of systems which are still under development, or which are already available (paragraph 2).

In a second stage of the project it is assessed which ADA-functions do different driver groups find most attractive with the selected level of intervention, and how important is the factor of the expected price of the system. In addition, drivers' expectations towards the systems effects on traffic safety, driving comfort, travel time and fuel consumption were of interest.

These preferences are assessed by a questionnaire study carried out in several European Countries (paragraph 3)..

In ADVISORS, these data will be combined with the results on a number of pilot tests, currently under way, to be able to develop implementation scenarios for those ADAS which are most promising in enhancing safety (first priority) and improving road network efficiency and reducing environmental load.

2. STATE OF THE ART

The State of the Art overview (Heijer et al, 2000) is structured hierarchically on the following distinctions: (1) phase, (2) the level of intervention (strategic vs tactical vs operational driver task level), (3) type of driver task support (perception vs decision making vs action) and (4) type of external infrastructural support needed (autonomous vs road infrastructure vs GPS/GSM)

2.1 Procedure: Structuring principles

Phase: Pre-crash: under conditions of free flow, encounters, and conflicts (driver behaviour directly influenced by impending conflicts with other road users). Crash: systems reducing damage. Post-crash: these are mainly systems assisting finding help. Almost all ADAS are in the pre-crash phase.

Level of Intervention: Strategic level: e.g. trip planning, selection of modes of transport, selection of route. Failure can result in a multitude of accident types. *Tactical level*: executing manoeuvres such as car-following: failure correlates with rear end (and also other) accidents; overtaking: failure correlates with head on (and also other) accidents; approaching intersections: failure correlates with side but also other types of impacts. *Operational level*: keeping the car on the road by steering and selection of the right speed. Failure correlates with single vehicle (and also other) accidents.

Type of Driver task support: At each of the levels in the driving tasks the following sub tasks are relevant: Perception, Decision making and Action. ADAS can assist the driver on one or more of these subtasks. E.g. Vision enhancement systems are merely supporting perception; Advanced Cruise Control systems cover all subtasks.

Feedback type: Five different types are considered: giving plain information to the driver, e.g. the distance to the car in front; giving general warning, e.g. that the car in front is closing in; giving advice to act, e.g. to slow down; communication with the environment and finally the system taking over the action completely.

Infrastructural support: Support needed by ADAS is categorised as follows: Autonomous in-car system; GPS/GSM support needed: e.g. navigation system and finally road infrastructure support needed: e.g. beacons or magnetic striping.

In the next paragraph, three types of Pre-Crash systems are presented, each system works at a different main level of Intervention, type of Driver Support, type of feedback, type of infrastructural support are involved.

2.2 Results

Navigation Systems. This feature will provide location and route guidance input to the driver. Varieties of the system will also support the various collision avoidance capabilities with road geometry and location data. The, nowadays standard systems, provide static navigation information. These systems will also provide the necessary capability to filter traffic information RDS-TMC (Radio Data System – Traffic Message Channel) to select those messages that are applicable to the vehicle location and route of travel. It will also offer the capability to recommend optimal routing based on driver preferences. More advanced versions of this service may integrate real-time traffic conditions into the calculations of optimal routes. An extra module will enable the receipt of information sent via GSM. The navigation display can also be used helping the driver when parking, using a camera viewing backwards.

Table 1 Navigation systems

Structuring principle	Specified type
Stage	Pre-crash
Intervention level	Mainly strategical; Tactical
Driver task support	Perception, Decision (support only)
ADAS feedback	Advice; Warning
Users	All
Vehicle type	Passenger & heavy vehicles
Road type	All
Scope	every time and everywhere and during all traffic and weather conditions, though it may not be optimal, when no up-dating of timely conditions is done
Support needed	GSM / RDS-TMC – infrastructure support

Techniques and technologies: The techniques are already developed and available.
Main actors – tests*:* All car suppliers, many tests have been carried out already.
State of maturity: Already marketed.
Forecasted cost*:* Around 2000 Euro, depending on sophistication; it is expected that the price will be lower in the future, as more units will be installed.
Market impact: It is already becoming standard in the higher class luxury cars.

Advanced Cruise Control (ACC & Stop and Go Systems). Longitudinal control ranges from normal cruise control to advanced cooperative intelligent cruise control. ACC systems function in the range of speeds above 40 km/hr; Stop and Go systems at lower speed. Intelligent cruise control senses the presence and relative velocity of moving vehicles ahead of the equipped vehicle and adjusts the speed of travel to maintain a safe separation between vehicles. Vehicle speed is adjusted either by allowing the vehicle to coast or by transmission downshifting. More advanced longitudinal control systems will be capable of detecting a vehicle ahead in the same lane, either moving or not. A full range of braking capability and operating speeds will be available to the equipped vehicle, including stop-and-go traffic operations (Oei, 1998a; Laurgeau and Bosseville 1999).

Table 2 ACC & Stop and Go systems

Structuring principle	Specified type
Stage	Pre-crash
Intervention level	Tactical; Operational
Driver task support	Perception, Decision, Action
ADAS feedback	Advice; Warning; Take -over
Users	All
Vehicle type	Passenger & heavy vehicles, buses
Road type	All
Scope	every time and everywhere
Support needed	Autonomous

Techniques and technologies: Radar, Lidar, vision are concerned.
Main actors: All car manufacturers and suppliers
State of maturity: First cruise control generation is existing for many years and proposed for all car manufacturers. More advanced and cooperative cruise control (Intelligent cruise control) is now proposed on the market by Jaguar and is to be introduced by Daimler Chrysler. More advanced functions, including stop and-go, are still under development. Relevant systems have been tested in EU co-funded projects AC-ASSIST (for highways, fully autonomous) and UDC (in urban environment, also infrastructure-supported).
Market impact: ACC is gradually penetrating the market and is expected to become actually standard vehicle equipment, thus greatly reducing the car following accidents on motorways.
User need sand evaluation of the system: Cruise control is convenient when there is little traffic on the road, so one can drive with the adjusted speed without interruption. When traffic is rather dense though, cruise control is not very convenient. ACC fulfils the need of the driver to continue driving in rather dense traffic conditions without the cruise control being switched off regularly.
Concerning extension of ACC to Stop and Go application, the relevant driving task is the automatic stop of a vehicle when such is needed, i.e. when the driver is unable or unwilling to do so.
Simulations and experiments with ACC show that this system can best be used on rural roads, where the traffic density is not too high. Traffic flow becomes more homogenous and there are less breakings, but more lane changes occur to evade a car in front (Oei, 1998a) Concerning Stop and Go, recent tests show room for improvement.
Expected effects: The probability of rear-end accidents with the car in front may reduce, but accidents from behind against the ACC car may rise (Oei, 19998a). Safety is expected to increase (FANTASIE, 1997) and it is technologically feasible. It could also decrease the direct costs for the transport user.
The system works well under standard conditions, the headway is adjustable, but in bad weather conditions, the main concern is that the sensors should be able to function without fault and in the case of a slippery road surface, the braking distance will be lengthened and a crash can still occur.
Relying too much on the system might reduce the attention of the driver structurally. Other ADASs can compensate this weakness.
Concerning Stop and Go, the weakness of the machine is the fact that it can brake down. An automatic test system should give the driver a warning when this occurs, so that the driver is put completely in command of the brakes.

Speed Control (Intelligent Speed Adaptation; ISA).

Speed control covers a wide range of different applications, from external speed recommendations to automatic speed reduction (limitation) function, integrated within traffic control systems (Oei, 1998b). The latter may be imposed directly to all the vehicles (or only equipped vehicles, i.e. trucks) within the control area through a Centre to call communication or indirectly, by managing the local traffic lights. Stop and go functions may be also included in this category, especially when implemented by an infrastructure-based system.
Techniques and technologies: The relevant implementation may be either based upon static sensors measuring the vehicles speed (located at sign posts and traffic lights) or on continuous communication of each vehicle speed to a Centre. In case of excessive speed, a Centre to Car communication may be used for speed reduction recommendation or imposal (by throttle and/or brake actuator) or the traffic lights may be regulated to implicitly stop the vehicles speed.
Main actors – tests. Various authorities (i.e. in Sweden and the Netherlands; Report on the ISA Pilot, Tilburg) have experimented with such systems. The car industry has provided relevant prototypes but there is no industrial consensus on it.

Table 3 ISA systems

Structuring Principle	Specified type
Stage	Pre-crash
Intervention level	Operational, Tactical
Driver task support	Perception, Decision, Action
ADAS feedback	Advice; Warning; Take over
Users	All
Vehicle type	Passenger & heavy vehicles, buses
Road type	All
Scope	every time and everywhere
Support needed	GPS –infrastructure information needed

State of maturity: Although such functions are mature, they are not existing in any actual vehicle. Infrastructure-based traffic lights adaptation has been installed in various test areas around Europe and is in service.

Market impact: Such systems are difficult to be implemented in the market due to poor industry- and user acceptance. It may be used initially for speed reduction of particular vehicle types (i.e. heavy trucks).

User needs and evaluation: From safety point of view, it is desirable to lower the speed of cars. From road authority point of view, increasing the efficiency and effectiveness of speed management is desired. From drivers' point of view, speeding is sometimes unintentional. Some drivers will prefer a warning system or a system preventing speeding, such as a speed limiter. A visual or auditory warning can be given when speeding, or discouragement of the driver by a counter force in the accelerator pedal. A mandatory system, or a system which may be overruled by the driver can make speeding impossible by reducing the fuel supply and/or by lowering the gear and lastly by braking.

Furthermore, there is a need for a dynamic speed managing system that adapts the speed according to the prevalent conditions of road, traffic and weather.

Jesty et al. (1999) add the following relevant characteristics for this type of system: The system shall be able to: (1) provide information about various aspects of the road network, e.g. default speed limits, road hazards, junctions etc; (2) display continuously to the driver the current mandatory speed limit; (3) offer the driver the ability to keep the vehicle below a new mandatory speed limit automatically (manual intelligent speed control).

Experiments are being conducted in Sweden - a few thousand cars are involved in four cities, only warning and discouragement of the driver are applied. In NL 20 cars and 120 drivers are involved, the system prohibits speeding, though an escape button is incorporated. Results from the Dutch experiments with a mandatory system show that driver acceptance increased with using the system, especially for use in urban areas, that safety increased. Driver interventions occurred very rarely.

Negative side effects may be that a warning system may be considered a nuisance and might be switched off. Furthermore, drivers may tend to drive with the maximum allowable speed, which still can be too high given the circumstances. Other ADASs can compensate this undesirable behaviour.

3. ACTOR POSITION

In an extensive questionnaire study (Mankkinen et al, 2001), 911 drivers of cars and heavy vehicles throughout Europe reported their expectations and preferences regarding several alternative ADAS and their combinations. The data were analysed by conjoint-analysis, which is proven to be well performing in terms of predicting preference and choice behaviour in marketing and service industries. An extensive description of the method is provided by Marchau et al. 2001. By this approach individuals have to indicate their overall preferences for hypothetical profiles (as comparable to products), described in terms of a set of levels of pre-specified attributes. Individuals are hereby explicitly forced to make trade-offs among attributes. In the procedure, it is assumed that: each individual derives a certain utility from each attribute-level (here: level of intervention or price-level), the so-called part-worth utility. Individuals combine part-worth utilities of separate attributes into an overall utility according to some combination rule, and choose an alternative based on a decision rule applied to the overall utilities. As profiles are constructed according to the principles of statistical designs the overall preference can be decomposed into the weights these individuals attach to separate attribute-levels, i.e. the so-called part-worth utilities, in creating their overall evaluation of alternatives. As such, it is possible to study the relationship between attribute-levels and overall preference behaviour in a more valid way than in an approach in which attributes are evaluated separately. The estimated part-worth utilities can be interpreted as deviations from the average profile rating (intercept) on an 11-point scale from zero to ten, with zero expressing extreme unattractiveness and ten expressing extreme attractiveness. Output from conjoint analysis includes importance ratings of the attributes showing preferences for attribute levels (alternatives), and correlations relating predicted ratings from the conjoint model with observed ratings. The conjoint analysis is based on least-squares estimation method.

3.1 Procedure

Three types of ADASs: ACC, defined to the drivers as **distance keeping;** ISA, defined to the drivers as **speed limiting,** and **Navigation** were chosen.

Alternative systems were presented based on their functional features with selected attribute levels (Table 4), different levels of system price and varying types of roads (one road type per driver) on which ADAS in question could be usable. The analysis was done with the help of SPSS Conjoint 8.0.. Please refer to Table 4 for an overview of the attributes and the chosen levels.
The different functionalities were described first with the attribute levels. Then the questions were listed, most of them with 5 response options, e.g. ranging from" "much more uncomfortable" to "much more comfortable". An example of a question:
"How will these technical functions change your driving comfort?"
The data were collected in Greece, Czech Republic, Italy, Germany, Netherlands and Finland. 82% were men. Ages ranged from 18 to 76 (with a mean of 38.3). Types of drivers were as follows: 907 luxury car drivers, 707 car/van drivers and 195 heavy vehicle drivers. Less than 5% had a navigation system installed, 46% of the heavy vehicle drivers had cruise control. ACC was known by 35%, 51% indicated prior knowledge on ISA. Navigation systems were familiar to 53% of the respondents.

Table 4 Attributes and their levels.

attribute	attribute levels		
ACC	distance warning	vehicle following	stop & go
ISA	no speed limiting	speeding warning	speed limiting
Navigation	no route info	static route info	actual route info
Price	€500	€1500	€2500

Two issues are reported here: (1) General attribute importance on all roads, and on motorways in particular; (2) Importance of the attributes with regard to expected safety. The drivers were also asked to assess the assumed safety impacts by scaling the assumed impact from '-2' to '+2' (where e.g. '-2' indicates 'much more unsafe' and '+2' indicates 'much more safe'). When considering the assumed safety; the price was not included to attributes.
Furthermore, the results are separated for types of drivers and types of roads.

3.2 Results

General preferences. With the selected attribute levels, the navigation function was considered to be the most important attribute influencing the overall attractiveness of the ADA system profile.
Expected safety impacts. The car drivers indicated the ISA function as being the most important and ACC function as being the second most important function when considering the safety impacts of listed ADA functions. However, the heavy vehicle drivers indicated the ACC function as being the most important and ISA function as being the second most important function when considering the safety impacts of listed ADA functions (Table 7 and 8).

Table 5 Attribute importance to overall attractiveness (all drivers).

	Motorways	Motorways +rural roads	All roads
ACC	12.93	13.34	13.18
ISA	19.42	21.09	25.17
Navigation	43.40	43.85	38.98
Price	24.25	21.72	22.67

The price of the system was considered to be the second most important attribute except on all roads (includes also urban roads), where ISA function was assessed to be more important than the price of the system. Overall, the ACC function influenced the overall attractiveness of the total system profile the least (Table 5 and 6). In contrast to the other categories, the heavy vehicle drivers find ACC most important and price least important attribute.

Table 6 Attribute importance to overall attractiveness for systems applicable on motorways.

	car private	car profes-sional	heavy vehicle
ACC	4.50	8.88	41.32
ISA	20.83	18.19	16.92
Navigation	42.66	44.99	37.80
Price	32.02	27.94	3.96
n	137	96	86

Table 7 Attribute importance of luxury car drivers and heavy vehicle drivers; the Safety model

	Car drivers	Heavy vehicle drivers
ACC	33.11	59.87
ISA	37.62	21.05
Navigation	29.27	19.08

With ISA function, only the speeding warning system was indicated as having a positive impact on traffic safety. From other parts of the results, it was found that the ISA limiting system was considered as being not attractive and this might have influenced their opinions when they were asked to consider the safety effect of the speed limiting attribution level.
With the ACC function, all drivers indicated only the warning level (distance warning) to have positive impact on traffic safety. Both vehicle following and

stop&go were considered to influence traffic safety negatively. With navigation function all drivers indicated both static and actual route information to somewhat increase the traffic safety.

Table 8 The safety model of heavy vehicle drivers

Attributes	part-worth utility	attribute importance
ACC		59.87
Distance warning	0.30	
Vehicle following assist.	-0.08	
Stop&go assistance	-0.22	
ISA		21.05
No support	-0.06	
Speeding warning	0.12	
Speed limiting	-0.06	
Navigation		19.08
No support	-0.09	
Static route info	0.02	
Actual route info	0.07	

4. CONCLUSIONS

Among car drivers the navigation function was found the most important function when considering the overall attractiveness of the ADA system profile with selected attributer levels. Heavy vehicle drivers indicated the navigation function as being the most important factor only in all roads environment; in motorway and rural roads environment the ACC function was indicated as being the most important function to heavy vehicle drivers. These results differ from the expectations based on the results of earlier studies (e.g. SARTRE): more drivers indicated ACC as being useful than ISA or navigation. This might be due to fact that the navigation system is nowadays better known among drivers and it has clear individual advantages to the driver. In addition, the drivers clearly have the choice of whether to use the system or not. Earlier studies (Comte and Carsten, 1998) support the findings that a pure advisory system would be more acceptable than one, which controlled driver behaviour in any way. Also in our study, drivers found the ISA warning system attractive, especially in non-motorway environment (urban areas).

In some new German cars there is the possibility to switch on ISA manually limiting the speed to the adjusted speed. The speed limiting system can be overruled by giving kick-down. Therefore, it can be concluded that a viable strategy for public authorities willing to introduce ISA for safety reasons would be to successively stimulate the addition of speed limits to the navigation system, then to stimulate the installation of a speed limit warning system and an overrulable volunatry speed limiting system. Later a mandatory speed limiting system can be considered.

With ACC, the most preferred attribute level (level of intervention) was the system only warning the driver. With the navigation function, navigation with timely route information was clearly the most preferred attribute level. However, heavy vehicle drivers indicated also the navigation system with static route information to increase the overall attractiveness of the system profile, especially on motorways and rural roads. Prices for the systems were selected between € 500 – € 2500. Price was considered the second most important factor except for heavy vehicle users to whom the investment costs of the system would probably be provided by their employers. For navigation systems, that is also the price for those systems presently on the market.

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REFERENCES

Comte, S. and O. Carsten, (1998). 'The effectiveness of ATT and non-ATT treatments for sharp curves on two-lane rural roads', in Swedish National Road and Transport Research Institute. In: *Proceedings of the Conference Road Safety in Europe – Vehicle safety-systems and components – The role of advanced technology for enhanced safety*, Bergisch Gladbach.

FANTASIE: *Forecast of New Technologies With Major Impacts*. Del. 9. November 1997.

Heijer, T. (Ed), (2000) *Problem identification, User Needs and Inventory of ADAS*. ADVISORS Del. D1/2.1

Jesty, P.H., H-J Schulz and A. Burkert, V Avontuur , J.F. Gaillet and G Franco (1999) *List of European ITS User Needs*. KAREN Del. D2.02.

Laurgeau, C. and J.M. Bosseville (1999) *Reflexion sur les systèmes de transports routiers futurs*. INRR'99 conference; Montpellier (France); 27-29 Septembre 1999

Mankkinen, E., Penttinen, M., Anttila, V., Marchau, V., Stevens, A. (2001) *Actor interests, acceptance, responsibilities and users' awareness enhancement*. ADVISORS Del. D2.2.

Marchau, V., Wiethoff, M., Penttinen, M. and Molin, E. (2001) Stated preferences of European Drivers regarding Advanced Driver Assistance Systems. *European Journal of Transport and Infrastructure research*, **vol 1,** pp. 291-308

Oei, H.L. (1998a) Advanced Cruise Control ACC. A literature study. SWOV, 1998.

Oei, H.L. (1998b) Intelligent Speed Adaptation ISA. A literature study. SWOV, 1998.

Report on the ISA Pilot Tilburg. AVV 2001.