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### Published paper

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# Safety Assessment of Driver Assistance Systems

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*This paper reviews issues in and procedures for the safety evaluation of in-vehicle Advanced Driver Assistance Systems. Contrasts are drawn between the two main areas of driver assistance systems — on the one hand information systems which interact with the driver and on the other hand intervening systems which interact directly with the vehicle. Navigation systems are typical of the former category and adaptive cruise control of the latter. It is argued that, for information systems it is possible to develop a “generic” safety assessment procedure, with a single generic test. A contrast is drawn with In the area of intervening systems (driver warning and vehicle control systems), where no such generic evaluation by means of a single test is possible. Such systems differ widely in their purpose, in their intended operating environment, in their functionality and in their operating envelope. The authors propose a structured procedural approach for the safety assessment of intervening systems.*

## 1. Introduction

Library shelves are bursting with a host of reports containing advice, guidelines, frameworks, checklists and statements of principle on the safety assessment of in-vehicle technologies for road vehicles. But there is still relatively little consensus on whether a single, generic approach can be adopted for the safety assessment of Advanced Driver Assistance Systems. Given this lack of consensus in the research and safety community, it is perhaps not

surprising that the authorities have not established a standard procedure, at either a national or an international level, for approving such systems before they come into production. This paper presents a critical review of current recommendations for the safety assessment of Advanced Driver Assistance Systems.

## **2. System categories**

The term Advanced Driver Assistance Systems (ADAS) can cover a full range of systems varying from systems providing information, advice and warnings, through systems that assist an/or intervene in vehicle control and manoeuvring tasks, all the way to systems that support fully automatic driving (Zwaneveld et al., 1999; Becker et al., 2000). Four broad types of ADAS may be distinguished. First of all there are systems intended to support various aspects of the driving task by providing information, commonly termed In-Vehicle Information Systems (IVIS). Typical examples are navigation systems and systems providing information on traffic and road conditions, such as TrafficMaster and RDS-TMC receivers. Secondly there are systems providing warnings or feedback, usually with the intention of reducing driver errors or violations. The informative (advisory) version of Intelligent Speed Adaptation, longitudinal collision warning systems, lane departure warning systems and lane-change assistant systems are examples of this category. The warnings may be auditory, visual or haptic (by force feedback or vibration). Thirdly, there are systems that intervene in vehicle control but without completely supplanting the driver, and in some cases permitting the driver to overrule system actions. Adaptive Cruise Control, Stop and Go and the various intervening forms of Intelligent Speed Adaptation fall into this category. Finally, there is automated driving, sometimes termed “autonomous driving”, in which the driver is completely out of the loop and cannot overrule system actions. Installing these various systems in vehicles changes the driver’s task, modifying certain components while others are added or removed. With the more intervening systems, the role of the human driver will to a greater or lesser extent be transformed from manual to supervisory control.

Vision enhancement systems are perhaps in a category of their own: while they may at first appear to be purely informational, like IVIS, they are more like systems that intervene in vehicle control in their impact on the driving task — the information flow is continuous and the systems fundamentally affect the relationship between the driver and the road environment. So perhaps vision enhancement systems should be included with the more intervening types of ADAS. The greater salience of relevant objects when using a vision enhancement system can perhaps be compared to receiving a warning.

## **3. Aspects of safety**

The safety implications of Intelligent Transport Systems have been commonly classified into three aspects (see e.g. Commission of the European Communities, 1991):

1. Functional System Safety, which covers safety problems from hardware design and from software design. The particular focus is on technical reliability, the propensity for system malfunction and the potential to go into a dangerous and/or unanticipated system mode.

2. Human Machine Interaction (HMI), which focuses on interaction between the user and the system. Key issues are the design and location of buttons, controls and screens (size, brightness); menus; means of dialogue between the user and the system; the channel for information exchange (auditory or visual) between the user and the system; and feedback to the user (auditory, visual or haptic). Inappropriate design can lead to overload (too much effort required) or underload (the user no longer involved in the main task of driving) or to distraction from the driving task at inappropriate times.
3. Traffic Safety whose concern is safe operation of the traffic system. It covers the outcome of both Functional System Safety and most but not all HMI problems (aspects of HMI design that do not affect safety, such as modes of operation not available while driving, are outside the traffic safety boundary). It also covers the ways in which the use of a particular system might influence road user behaviour and alter the interaction between the driver, the vehicle, the road infrastructure and other road users (including vulnerable road users such as pedestrians and cyclists) in such a way that safety is affected.

The relationship between these three aspects of safety is illustrated in Figure 1.

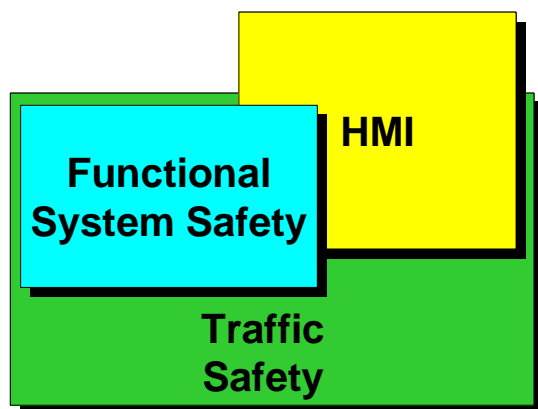


Figure 1: The three aspects of safety

Different types of system will give rise to different concerns about safety, as summarised in Table 1. Safety concerns with totally automated driving are primarily those of functional system safety — is the software reliable, what happens if a sensor fails, will the system work under various meteorological conditions, etc. With IVIS, the major safety concerns are about HMI aspects, such as comprehension, distraction and workload. With systems that warn the driver or intervene in vehicle control, the major concerns are about traffic safety — is the driver out of the loop and therefore suffering from loss of situation awareness, do negative behavioural adaptations arise. However, HMI aspects, such as the driver's comprehension of system functionality and system capabilities, may also be significant concerns with these two system categories.

**Table 1: Safety concerns with different types of ADAS**

<b>Intervention level of system</b>	<b>Intention of system designers</b>	<b>Primary area(s) of safety concern</b>	<b>Major issues</b>
Information	Provide information beyond that available from the road and traffic environment	HMI	Distraction or overload lead to driver errors
Warning and feedback	Reduce errors and/or violations	(HMI and) traffic safety	As above + driver over-reliance on the system
Intervention in vehicle control	Increase comfort and/or safety	(HMI and) traffic safety	As above + misinterpretation of system capabilities
Automated driving	Increase road capacity, improve safety and free the driver for other tasks	Functional system safety	System reliability and need for driver intervention in case of malfunction

#### **4. System life cycle**

In addition to system type and the three aspects of safety, there is a third dimension that has to be considered in the safety assessment of driver assistance systems. This is the stage of development of the system, or the system life cycle. A generic life cycle for intelligent transport systems, showing the relationship between stage of development and safety aspects, is presented in Figure 2. Numerous sets of guidelines have been produced over the years, containing recommendations on safety issues and recommended procedures for the various stages of system development (Noy, 1998; Carsten, 1999).

From Figure 2, it can be seen that, as an approximate rule of thumb, Functional System Safety aspects are to be studied early in product development, the HMI should be validated in mid-development and traffic safety validation can only be achieved in the real world by means of field trials, in so-called “retrospective” traffic safety evaluation. There is no predictive safety science which can reveal in advance how users will respond to a system, and therefore no methodology other than empirical experience which can reveal whether a particular system is safe in use. This is not to deny that there is knowledge of human performance and models of human behaviour which can provide guidance in designing an appropriate and thorough safety assessment. Without sensible hypotheses, to provide guidance on issues of concern and scenarios to examine an evaluation is likely to be wasted.

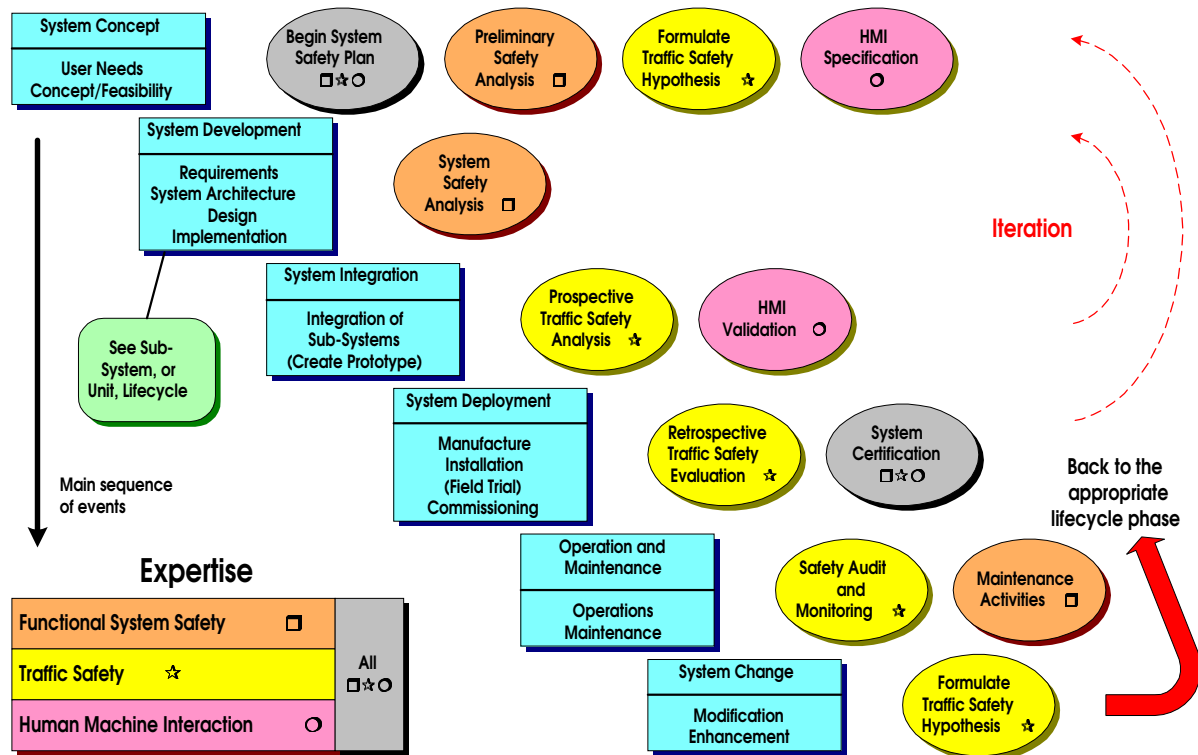


Figure 2: Life cycle for the safety of an ITS System (from UTMC22, 1999)

## 5. Towards a generic safety assessment of in-vehicle information systems

### 5.1 Alternative approaches

As indicated in Table 1, the primary area of safety concern with in-vehicle information systems is with the effects of the HMI on user performance. There are three types of broad approach which can be applied for the assessment of HMI (Parkes, 1995):

1. We can establish **product or design standards**. These take the form of specifying the physical aspects of the system, for example a minimum screen size or a particular layout of the control buttons. The standard computer or typewriter keyboard is a typical example. Product standards are easy for the designer to follow, but they suffer from the drawback that they are technology-dependent and therefore tend to stifle innovation. They also do not guarantee the usability of the entire system or the safety of driving while using the system.
2. We can develop and stipulate **procedural standards**. These take the form of prescribing a programme of analysis and testing to be used in product development (ISO 9000/9001 is the best-known example). Procedural standards generally require an inspection or certification authority to enforce their use; they often require extensive documentation; and they can be laborious to apply. In the case of in-vehicle HMI, they will not *guarantee*

safe driving performance, but of course they can protect the system manufacturer who can show that rules, regulations and advice were followed in the system design process.

3. We can impose *performance standards*. These specify a minimum level of performance which must be met while the system is being used. In the case of IVIS, they might specify a minimum level of performance for the primary task of driving or for the secondary task of interacting with the in-vehicle system. Performance standards are technology independent and do not limit innovation. If they require an assessment of performance in the primary task of driving, they can provide an objective assessment of whether a minimum level of safety is met. However, they require research effort for their development and validation, and in actual use they may require testing by a particular test house or with specific equipment.

In the automotive world, technical performance standards are quite common in the vehicle design area, notably in such areas as braking and crashworthiness. Product standards are surprisingly infrequent, so that not even pedal placement is specified by regulation.

## 5.2 Guidelines and checklists

In the area of HMI for in-vehicle information systems, the primary focus has been on the development of procedural guidelines and pre-standards. Ian Noy (1998) has proposed that such procedures could form the basis of a “process-oriented standard” for safety assurance, modelled on the ISO 9000 series, which could be adopted by industry voluntarily or even be imposed by governments as a requirement. The original such guidance was the PROMETHEUS MMI Checklist (Nilsson and Alm, 1991) which was produced in 1991 and was followed by the DRIVE II HARDIE Design Guidelines (Ross et al., 1995) and Handbook (Ross et al., 1996). Further elaboration and refinement has led to the UK Safety Checklist for the Assessment of In-Vehicle Systems (Stevens et al., 1999) with a 12-page form, 5 pages of instructions and 26 pages of supporting information. However, for answering a particular question such as “Is the IVIS free from reflections and glare under all ambient light conditions?”, an extensive set of reviews and tests may be required.

There is little doubt that following the procedures recommended in such checklists can help to produce a better-designed system and to identify design errors and problems and thus contribute to safer systems. But the sheer laboriousness of the procedures recommended is likely to mean that shortcuts will be taken. Perhaps more serious, the procedures are in the main subjective and cannot provide a certainty that a minimum level of safe performance in driving has been met. A current Swedish research initiative, the SafeTE (Safe Test and Evaluation) project, is aiming at extending recent checklists with a behavioural evaluation and also at including explicit safety estimates as a pre-stage to pass-fail criteria.

In terms of the laboriousness of such checklists, there has been considerable effort at both national and European levels to reduce them to a set of major principles. The outcomes are the UK Code of Practice (Department of Transport, 1994), the German Code of Practice (Wirtschaftsforum Verkehrstelematik, 1996), the ECMT Statement of Principles of Good Practice (ECMT, 1995) and, most recently, the European Statement of Principles on Human Machine Interface from the HMI Expert Task Force (European Commission, 2000). But such codes suffer from the fact that, while they enshrine very worthy principles of good design, they do not provide a regime for *assessing a design*.



Indeed this lack of a regime is acknowledged explicitly in the European Statement of Principles and the associated document, the Expansion of the Principles (European Commission DGXIII, 1998). For example, the section of the document on overall design principles states: “The system should be designed in such a way so that the allocation of driver attention to the system displays or controls remain compatible with the attentional demands of the driving situation.” This is a worthy and incontrovertible statement and it is hard to quarrel with the rationale that is given in the Expansion of the Principles: “To ensure that the driver’s ability to be in full control of the vehicle is not compromised by the use of a driver information or communications system”. The expansion of the principle continues with a set of definitions. Thus attentional demand is defined as “the physical and mental ‘resource’ required at any instant to successfully perform a particular task”. In relation to this definition, it is pointed out that the attentional demand of driving varies with the driving situation and that attentional demand from interacting with system displays and controls will also vary. However, when it comes to the point at which a set of procedures might be expected on how to evaluate compliance with the principle, the document dodges the issue and states: “No specific assessment of a system according to this Principle is envisaged.” The guidance provided by the Statement of Principles on information presentation is as follows:

- Visually displayed information should be such that the driver can assimilate it with a few glances which are brief enough not to adversely affect driving.
- Where available internationally and/or nationally agreed standards related to legibility, audibility, icons, symbols, words, acronyms or abbreviations should be used.
- Information relevant to the driving task should be timely and accurate.
- The system should not present information which may result in potentially hazardous behaviour by the driver or other road users.
- The system should not produce uncontrollable sound levels liable to mask warnings from within the vehicle or outside.

Here again, the Expansion of the Principles offers no advice on how compliance with this guidance should be assessed and once again states in relation to the statement about information which could produced hazardous behaviour: “No specific assessment of a system according to this Principle is envisaged by the Task Force.”

We are thus left with a somewhat unsatisfactory situation. Both the research community and the authorities have recognised the dangers inherent in HMI designs that can overload or distract the driver. Some quite elaborate checklists with detailed advice on assessment procedures have been developed, but these have no pass-fail criteria and there is no legal requirement for compliance. On the other hand, the European Commission has recommended to the motor manufacturing and supply industries that they should comply with the Statement of Principles, and has invited member states to encourage industry to adhere to the principles. The Commission has further indicated that the member states are to provide the Commission by December 2001 with a report on adherence to the principles. This would be all very well apart from the facts that the principles are so vague as to be meaningless and that there is no means of establishing compliance with any of them, since advice on specific assessment is excluded.

Of course checklists can be used in a different way — as initial screening tools to develop hypotheses about a system rather than as evaluation tools in themselves. A checklist for use

as a screening tool for the evaluation of in-vehicle information systems has been developed in a Dutch national project (Brookhuis, Van Winsum, Heijer and Dynstee, 1999). A similar approach was adopted in a cross-modal European research project on the human implications of new technology (Carsten, 1998).

### 5.3 Performance tests

As an alternative to such advice and guidance, there have been a number of attempts at creating performance tests that focus on users' interaction with an In-Vehicle Information System. One approach has concentrated on the *cognitive* load imposed by the task; another approach has focused on the *visual* distraction. For both approaches, the claim is made that the test procedure can be applied in a laboratory environment without the involvement of any driving task, in other words the procedure only examines the secondary task and the driving context is removed from the assessment.

Tests for evaluating cognitive load work by simulating and evaluating the user task and producing a qualitative rating or quantitative score of task complexity and difficulty. One example is DIADEM (Dialogue Design and Evaluation Method), which is a commercial product that was applied for road-vehicle HMI evaluation in the DRIVE II EMMIS project (Nirschl, Blum and Eck, 1995; Nirschl and Eck, 1993). In DIADEM, the user tasks in dialogue with the system are represented as a series of formal steps (if x, then y). Tasks that require reference to user knowledge are distinguished from those that merely require simple response to system prompts. In addition, situation-dependent actions are distinguished in order to identify the need for reference to the state of the vehicle or the environment. Once all the action steps required have been specified, a production rule set is generated. From this rule set, complexity measures (e.g. learning effort, execution time, visual distraction) are derived in order to evaluate the system. DIADEM and similar methods have been subjected to two major criticisms. Firstly, tasks that are conceptually more complex in terms of production systems theory, may not be more difficult to perform in actuality (a good example is catching a ball). Secondly, the evaluation is to be carried out as a primary task, i.e. it is divorced from the actual driving context. This criticism has also been made about the application of DIADEM in the aviation domain where it has been stated that the method "[does] not take account of the timing and multi-user aspects, and has little regard for the context" (Valot et al., 1997, p. 123).

The "15-second rule", which is a recommendation of the SAE (Society of Automotive Engineers) Safety and Human Factors Committee stipulates a minimum level of performance in using an in-vehicle navigation system (Green, 1999a; Green, 1999b; Farber, 2000). The rule is intended to outlaw systems that require the driver to take his or her eyes off the road for too long, but, in order to simplify the measurement task, it actually measures total task time rather than glance frequency or glance duration. The proposed standard stipulates that the total task time, for any task permitted by a navigation system while the vehicle is in motion, should be no longer than 15 seconds. However the actual measurement is not done with an actual system while driving. Rather, it is done in the laboratory as a static task using a prototype or mock-up of a system

A number of issues arise when considering the 15-second rule. One question is whether static and dynamic task times are correlated — there is no inherent reason to believe that the rankings of tasks when performed statically will be the same as the ranking of those same

tasks when performed dynamically. Another problem concerns whether dynamic task time is correlated with “eyes off the road time”. For example, some tasks requiring manual input can be performed with only minimal visual confirmation or even without the driver taking his or her eyes off the road, while others may require substantial glance time. Therefore task time and “eyes off the road time” may not correspond: one could get a task with long duration that is performed safely because the driver is able to keep his/her eyes on the road.

In addition, the validity of the total task time concept has been disputed. It has been found that drivers tend to “chunk” large tasks into smaller sub-tasks of between 1 and 2 seconds glance duration (Zwahlen et al., 1988; Wierwille et al., 1988; Dingus et al., 1989). Using total time on task as a surrogate measure for safety implies that ten glances, each of 1.5 seconds duration are less safe than a single 14-second glance. Finally, the method ignores cognitive load. There is evidence that cognitive load can lead to distraction and reduced Situation Awareness. Car phone studies have shown, for example, that the driving task is not only affected by the use of a phone while driving, but also by the content of the phone conversation that is conducted (Parkes, 1991; Lamble et al., 1999).

It can be argued, therefore, that cut-down performance tests are implausible tools on theoretical grounds and, moreover, have not been properly validated. Perhaps their greatest deficiency is the removal of the context of the driving task. But there are substantial attractions to the performance approach. A performance test uses objective and verifiable criteria as opposed to the subjective judgements that have to be used when using a procedural approach. Unlike design standards, performance standards do not create any roadblocks to innovation by freezing current practices. Indeed they free the product developer to use any design whatever, provided that, in the end, the outcome can be shown to meet a minimum level of performance.

There is considerable force of logic to using performance in the primary task of driving as the gold standard, rather than using performance in the secondary task of interacting with an IVIS. The primary task approach is more realistic in that it does not remove context but requires consideration of context, has greater face validity and creates indicators that are more obviously related to safety than task time or task complexity. There has been considerable acknowledgement of the need to focus on driving performance as the yardstick. For example, a U.S. Human Factors workshop in 1997 identified research on the role of task load in perception and decision-making and the influence of such task load on driver behaviour as the number one human factors research need in the area of Intelligent Transport Systems (Battelle Research Group, 1998).

#### **5.4 The HASTE initiative**

The new European HASTE (Human Machine Interface And the Safety of Traffic in Europe) project, funded in the Fifth Framework Growth Programme, is focussed on addressing this need to look at the influence of task load on driver behaviour. The aim of HASTE is to develop a procedure to quantify safety problems with IVIS with a view that this procedure can eventually become the basis for an objective performance standard.

The objectives of HASTE are to:

- Identify traffic scenarios in which safety problems with an IVIS are more likely to occur;
- Explore the relationships between task load and risk in the context of those scenarios;
- Understand the mechanisms through which elevated risk may occur in terms of distraction and reduced Situation Awareness; and
- Identify the best indicators of risk in terms of accident surrogates.

The overall approach of the project is illustrated in Figure 3. Visual demand and cognitive load will be studied both separately and in conjunction. Initially, they will be manipulated through artificial tasks which impose either visual distraction or mental load. The effects of these tasks in the context of various driving situations will be monitored and drivers' situation awareness and driving performance measured.

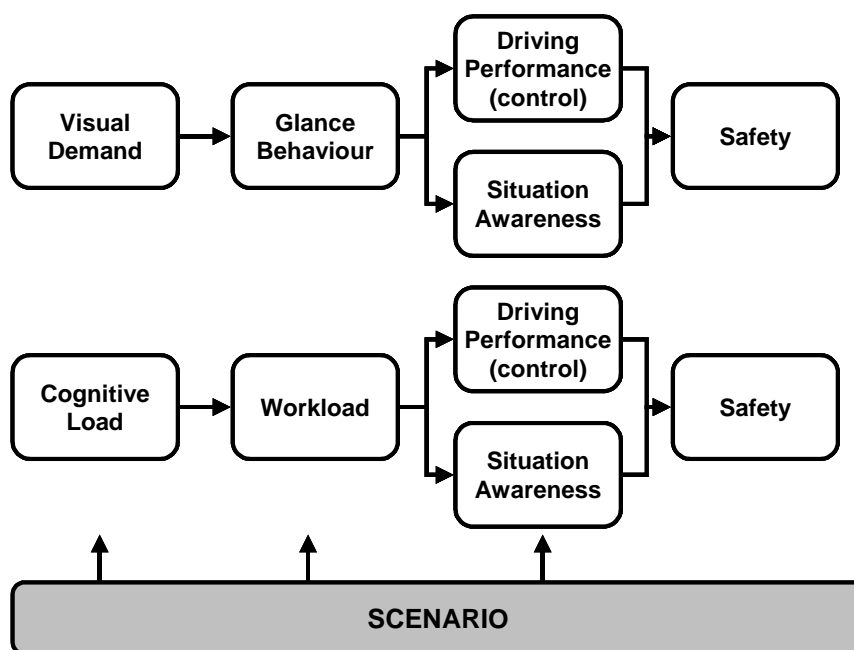


Figure 3: The HASTE approach

The hypothesis is that, with increased visual and/or cognitive load, risk will increase exponentially, as it does for many other safety problems including speeding and alcohol impairment. If confirmed, the exponential relationship will permit the selection of “critical” level of risk to be made on statistical grounds. The exponential relationship is shown in Figure 4, which also illustrates that much of the experimental studies in HASTE will be, for obvious practical and ethical reasons, carried on various driving simulators. At lower levels of demand, complementary studies will be carried out in real traffic with instrumented cars. This will allow some validation of the simulator-based studies.

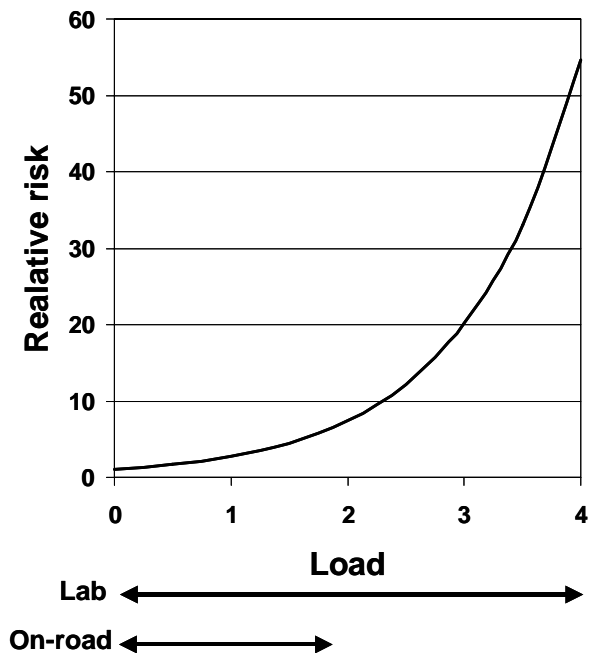


Figure 4: Hypothesised increase in risk with task load

In a subsequent phase of the project, the traffic scenarios and safety indicators will be applied to the evaluation of real in-vehicle information systems. The major output will be a pre-deployment test regime for general use which can eventually serve as the basis for a formal approval process. This generic regime, which could be applied to determining whether any IVIS is safe for actual use, will obviously have to be practicable and cost-effective as well as properly validated. Specific groups of users, such as novice and elderly drivers will have to be considered carefully in designing the regime.

## 6. Can the same generic approach be applied to warning and intervening systems?

As discussed in Section 2, Driver Assistance Systems extend beyond purely informational systems to ones that warn the driver or intervene in vehicle control. Such warning and intervening systems will have very different effects on driving from IVIS. Whereas the safety concerns with IVIS are about overload and distraction, with these systems the concerns are about underload, overreliance on the system, misunderstanding of system functioning, system mode confusion and behavioural adaptation.

### 6.1 Underload

Systems that automate parts of the driving task, such as ACC and other forms of semi-automatic longitudinal control, may reduce driver workload and lead to reliance on the system, i.e. “automation induced complacency”. It has been suggested (Parasuraman, Molloy and Singh, 1993) that automation of part of the driving task may lead to driver underload and

hence loss of situation awareness. Situation awareness can be regarded as consisting of three levels — perception of elements in the current situation, comprehension of the current situation and projection of future status (Endsley, 1995).

Perhaps the most dangerous situation is low demand driving followed by a critical high-demand or high-workload event, which could occur if a driver assistance system is not able to cope with a situation and therefore driver intervention is required. Bainbridge (1987) has pointed to such automation-induced complacency as one of the “ironies of automation.”

Experimental work has confirmed that low workload can potentially lead to loss of situation awareness and a resulting inability to respond in time to critical events. In an experiment investigating ACC carried out on the VTI driving simulator, drivers approached a stationary queue on a motorway (Nilsson, 1995). The ACC was set not to detect stationary objects so that the drivers had to detect the queue and slow down the vehicle appropriately. The design was a between-subjects design with ten drivers assigned to the ACC group and ten to the non-ACC group. In the ACC condition five drivers crashed into the queue; in the non-ACC condition one driver crashed. The author suggests this was due to drivers misunderstanding the system and expecting it to respond in such situations, especially as the ACC had previously been able to cope with analogous situations without a need for manual intervention. The drivers realised too late that the ACC would not handle the situation and that they had to intervene.

A similar experiment was conducted on the HUSAT simulator at Loughborough University. Drivers were exposed to a stationary queue at the end of a one-hour driving session on a two-lane highway. Fifty-six drivers participated with half assigned to the ACC condition and half driving in the non-ACC condition. The result of the experiment was that minimum time-to-collision into the stationary queue was significantly shorter with ACC (Richardson, Ward, Fairclough and Graham, 1996).

It appears that problems occur when drivers are required to regain control of a previously automated system. Stanton et al. (1997) reported such effects for an ACC system and Desmond et al. (1998) for an automated lane guidance system. The authors comment that the results strongly support *human-centred* strategies, whereby the driver is involved in the driving task, and indicate that such strategies are superior to total automation.

With the introduction of ADAS, the role of the human driver will be transformed from manual to supervisory control, i.e. observing the interaction of the system with the environment. Such supervisory control can be seen as a more difficult human task than manual control, since the demand on human cognition is increased, while the demand on human action is decreased (Wickens, 1992). We therefore get the worst combination: low arousal and high momentary stress when things go wrong.

## 6.2 Misunderstanding of system functioning

A type of error that can occur with intervening systems is that drivers may misunderstand the performance envelope of the system. Drivers will not necessarily understand the limitations of the technologies underlying an in-vehicle system or the constraints imposed by the designers on system operation. This could arise with an Adaptive Cruise Control. After experiencing the fact that the system is capable of considerable deceleration (some ACCs have braking capability that encompasses 80 or 90 percent of the distribution of driver braking severity), drivers may interpret an ACC as a collision avoidance system. As a result,

drivers may tend to be slow in resuming manual control when a critical situation does develop, anticipating that the ACC will be able to cope. This is what Fancher and Ervin (1998) have termed the “authority” issue — how much authority does the ACC have over the operation of the vehicle.

With driver assistance systems that intervene in or take over part of vehicle control, one part of the driving task is now monitoring the operation of the system rather than interacting directly with the vehicle. This interaction will take place both directly through whatever interface is provided by the car manufacturer, and indirectly through sensing system operation. One crucial aspect of such monitoring is the detection of faults and failures in the system. Bainbridge (1987) has pointed out the poor performance of humans in monitoring tasks.

Equally, mode errors of the type that have been reported in aviation human factors with complex automated flight systems may arise: the driver may not be aware of whether the system is enabled or disabled, or in which mode it is currently operating. This could mean that the driver’s intuitive prediction of how the system will function may be inaccurate. With ACC, the driver may not be aware of whether the ACC is enabled or disabled, is in “pure” cruise control mode or in headway mode. After leaving a motorway the driver may forget that the ACC is still on. As systems become more complex and start to combine various functions, such errors may become more likely.

### **6.3 Behavioural adaptation**

The new vehicle control systems have direct effects on driver behaviour through system parameters. Thus with Adaptive Cruise Control the minimum time headway permitted by the vehicle manufacturer will prevent the driver from adopting a smaller headway without switching the system off or into standby. Similarly with Intelligent Speed Adaptation, maximum vehicle speed will, with a mandatory version, be set by the system. But there is overwhelming evidence that, beyond these direct engineering effects of the systems, drivers engage in further, indirect modifications of their behaviours when using these new devices. These indirect changes in behaviour are often termed “behavioural adaptations.”

The standard definition of behavioural adaptation from the OECD report of 1990 is: “Behavioural adaptations are those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which are not intended by the initiators of the change.” The report continues: “For behavioural adaptation to occur, it must be assumed that there is feedback to road users, that they can perceive the feedback (but not necessarily consciously) that road users have the ability to change their behaviour, and that they have the motivation to change their behaviour” (OECD, 1990).

There is already a considerable literature on behavioural adaptation to ADAS. Some examples of adaptations to ACC can be used as illustrations of the phenomenon. An experiment was conducted on the University of Groningen driving simulator with 38 subjects (Hoedemaeker, 1999). The subjects first drove a motorway route without ACC and subsequently drove the same route three more times, each time with a different version of ACC out of a total of six alternative versions. The ACCs varied in terms of the set time headway and in terms of whether the system could be overruled in headway mode by use of the accelerator or brake. All the ACCs had sufficient “authority” to bring the vehicle to a safe stop. With ACC, speeds increased in both light and heavy traffic situations. Standard

deviation of lateral position increased with ACC, particularly in heavy traffic, which is not likely to be beneficial to safety. Use of the left (fast) lane also increased with ACC, presumably because of the higher speed choice.

In the same experiment, differences were found by driving style. Fast drivers identified by the Driving Style Questionnaire of West, Elander and French (1992) increased their standard deviation of lateral position with ACC while driving in light traffic, whereas slow drivers decreased their standard deviation of lateral position in the same situation.

Driving style was also investigated in the Michigan Field Operational Test (Fancher et al., 1998). Here driving style was classified on the basis of actual speed and headway choice. From most aggressive to least aggressive, the categories were hunter/tailgaters, extremists, planners, flow conformists and ultraconservatives. It was found that the first group used the ACC relatively less often, in all probability because the system's minimum time headway of 1.1 seconds was larger than the drivers' preferred time headway of 0.6 to 0.8 seconds.

What these examples make clear is that such adaptations can be anticipated but they cannot be predicted, certainly not in their precise form. In a recent comment on the unpredictability of economic forces, Alan Greenspan, the chairman of the U.S. Federal Reserve, declared: "[Do we] have the capability to eliminate booms and busts? The answer, in my judgment, is no, because there is no tool to change human nature or to predict human behaviour with great confidence." (Financial Times, 26 May 2001) This same message applied in the area of Driver Assistance Systems. We know that humans will find ways to maximise their personal benefits from the systems, and once we observe those adaptations we can generally understand them. But without observing them, we cannot predict them. Thus empirical studies, informed by reasonable hypotheses, are a necessity if we are to learn how these systems will actually be used.

#### **6.4 The necessity of a process-oriented approach**

The need for empirical studies drives us back to the process-oriented approach advocated by Noy (1998). But whereas Noy's main concern was with IVIS, the process-oriented approach seems more appropriate for warning systems and the various Driver Assistance Systems that intervene in vehicle control. Such an approach has recently been advocated by the European RESPONSE project (Cieler et al., 2000). The RESPONSE approach is a three-step procedure. The first step is full functional system safety evaluation. The second major step is one or more controlled, short-term and accompanied drives, which should involve specific risk groups such as inexperienced, elderly, cognitively-impaired and risk-prone drivers. At this stage, specific potential problem scenarios, identified by earlier "risk identification" are investigated. And the third step is an unaccompanied long-term experiment, i.e. a field trial in which the system is used for several weeks.

This approach is eminently sensible (and, it could be argued, not that different from the advice produced in earlier projects or the process depicted in Figure 2). What is needed in addition is a formal quality assurance procedure as advocated by Noy (1998), involving detailed record keeping, to cover all decisions and information used in the design and product development process, as well as an audit process that allows both internal and external audits. In the long run, we should perhaps move to a formal certification process for the approval of new ADAS.



One initiative in this direction is another European project, ADVISORS. The project aims include: definition of implementation scenarios and key actors; analysis of foreseen technical and behavioural risks of various ADAS; identification of barriers to ADAS implementation and the importance of human factors for their successful deployment; definition of measures and strategies to overcome identified barriers; and development of a common impact assessment methodology.

In spite of such efforts there are still some crucial unresolved issues. One problem area is the formulation of the behavioural and safety hypotheses about a system as part of the risk identification procedures. Without appropriate hypotheses, subsequent evaluation may well be at best ill-informed and at worse pointless. This topic is addressed by the CODE Road Safety Guidelines (Draskóczy et al., 1998) which provides a structure for the generation of hypotheses in the form of a kind of checklist and which gives examples of the kinds of hypotheses that can be generated about a variety of ITS applications. But the problem is not just one of advice on how to generate sensible hypotheses. It is also one of transparency in the process of doing so. Ideally, there should be consultation with outside experts and a documented audit trail of that discussion. That documentation could then be used in any subsequent product approval or even in product liability lawsuits.

Another problem area is that of translating observed results, gathered in simulator studies, controlled drives, and uncontrolled field trials into predictions about safety changes. It is notoriously difficult to take data about changes in driving performance or behaviour and translate those findings into predicted changes in accident numbers. It is even more difficult to consider scenarios in which vehicles are on the road with a variety of ADAS, including in some cases multiple ADAS. Here microsimulation modelling offers the promise of a solution (Carsten, 2001). Microsimulation models could be “educated” with information generated from off- and on-road trials on both driver errors (from, for example, reduced Situation Awareness) and behavioural adaptation to new systems. The same models could produce safety predictions, in the form of near misses, which would be analogous to the traffic conflicts sometimes used in the safety evaluations of more traditional schemes. But we are a long way from having such models, and a considerable effort will be required to generate them, although some first, tentative steps have begun. One example is the SINDI project (Safety Indicators – a basis for assessment of safety effects of Intelligent Transport Systems) (Lind et al., 2000). Here the intention is to collect and use behavioural knowledge (data) as input to the micro-simulation model, while an expert system will be used to interpret the output from the micro-simulation (safety indicators) in terms of probable effects on traffic safety.

## **7. Conclusions**

There is no inherent reason why the same safety assessment approach should be applied across all Driver Assistance Systems. For pure information systems, of which navigation systems are the most obvious example, there is a reasonable prospect of generating a standardised performance assessment which can both free designers to innovate and permit the authorities to assure themselves that safety is not harmed. But for systems that provide warnings or intervene in vehicle control, a generic test is not feasible. Here the structured process-oriented approach is appropriate. But this approach needs to be further specified and

enhanced, for example through defining common test scenarios and indicators for various sub-categories of warning and intervening systems. The rationale for utilising common scenarios and indicators across assessment activities is that it would provide the possibility of comparing the results and so enhance the power of the experimental work.

A safety assessment will only be as good as the hypotheses that initially inform it. And we are still not able to translate complex and often contradictory results expressed in terms of a variety of safety indicators (variation in lane position, reaction time, car following behaviour) into reliable estimates of changes in safety in a road network. Here there is large potential for using microsimulation models, but their development will be no small task.

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