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Literature review of behavioural effects

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Authors		**F. Saad, M. Hjälmdahl, J. Cañas, M. Alonso, P. Garayo, L. Macchi, F. Nathan, L. Ojeda V. Papakostopoulos, M. Panou, E. Bekiaris.**	
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List of abbreviations

ACC : Adaptive Cruise Control

ADAS : Advanced Drivers Assistance System

CAS : Collision Avoidance System

ICC : Intelligent Cruise Crontol

ISA : Intelligent Speed Adaptation

LOC : Locus of Control

SS : Sensation Seeking

SA : Situation Awareness

HUD : Head Up Display

Glossary

Behavioural adaptation in Psychology: "The whole set of behaviour changes that are designed to ensure a balance in relations between the (human) organism and his surroundings, and at the same time the mechanisms and processes that underlie this phenomenon". "Adaptation processes come into play each time a situation embodies one or several new, unknown or simply unfamiliar elements. These processes are said to be assimilating when they integrate the new data into previously established patterns of behaviour, and accommodating when the new data transform an existing pattern or schema in such a way as to make it compatible with the situation" (Grand Dictionnaire de la Psychologie).

Behavioural adaptation in road safety research: In road safety research, the term "behavioural adaptation" is mainly used to signal unexpected or unanticipated behavioural changes that appear in response to the introduction of a change in the traffic system and which may (more or less) jeopardise its expected safety benefits. An OECD expert group (1990) defines behavioural adaptation as "those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change".

Complacency is defined as a feeling of being at ease satisfied or comfortable. In the aviation Human Factor domain the term is used to characterize pilot's over reliance on automation.

Direct and Indirect behavioural effects of driver support systems: when studying behavioural adaptation to driver support system it is important to adopt a *multi-level approach* that takes into account direct and indirect effects, i.e., to examine the impact of the support system on the performance of the specific driving sub-task to which it is dedicated (direct effects) as well as its potential impact on the performance of other driving sub-task (indirect effects). This also means studying possible changes within the activity of "assisted" drivers as well as within their interactions with other road users.

Driving style: Basically, the driving style is described as a relatively stable characteristic of the driver, which typifies his/her personal way of driving, the way he/she chooses to drive (for instance, the level of speed or the safety margins more frequently adopted, the general level of attention devoted to the driving task and so on). The driving styles is most often defined in contrast to driving skills, see for example, the definition given by West et a., 1993: "A driving style is defined as the manner in which a person chooses to drive, in contrast to driving skills which reflect the way in which a person is able to drive.

Learnability of driver assistance system: "a system is learnable, if accurate assimilation of information by the driver occurs, evidenced in the driver's understanding of system function, system handling and situational limits" (RESPONSE project).

Locus of Control: Locus of control (LOC) relates to an individual's assumptions regarding responsibility for the outcome of events (Rotter & Hochreich, 1975). Internals believe they are able to act so as to maximize the possibility of positive outcomes and minimize the possibility of negative outcomes. Externals believe…

“Self-explanatory” support system”: a self explanatory support system is defined as a “driver assistance system leaving a minimal amount of learning demand to the driver and eliminating learnability issues which can result in safety-critical traffic situations”. (RESPONSE project).

Sensation Seeking: According to Zuckerman (1994), sensation seeking (SS) ‘is a trait defined by the seeking of varied, novel, complex, and intense sensations and experiences and the willingness to take physical, social, legal, and financial risks for the sake of such experiences’. Central to this trait is ‘the optimistic tendency to approach novel stimuli and explore the environment’.

Situation awareness. Originally a term used in the aircraft pilot, situation awareness has developed as a major concern in many other domains where people operate complex dynamic systems. Situation Awareness (SA) is formally defined as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” (Endsley, 1988a).

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Executive summary

This review of the literature is aimed at identifying the main types of problems that arise in the study of the behavioural adaptation induced by different driver support systems. Thus, the review does not necessarily seek to be exhaustive, but rather to highlight the issues to be considered prior to planning the experiments to be conducted during the Sub-Project 1, and the identification of the most relevant parameters and variables that affect driver behaviour for modelling purposes.

The report is structured as follows:

The first chapter proposes a synthesis of the main types of problems concerning the study of behavioural adaptation induced by the different driver support systems.

The next four chapters are devoted to a synthesis of studies on two main types of Advanced Driver Assistance System, ADAS (ISA, ACC) and on the mobile phone use, and to a more general examination of the consequences of automation in another area of transport research – aviation.

The sixth chapter contains a synthesis of the different variables and parameters that are normally used to study and evaluate driving behaviour.

Lastly, the seventh chapter proposes an evaluation scheme for studying long-term effects in driving behaviour.

A series of annexes organised in function of the systems studied contains a detailed summary of the different research studies that were analysed in depth.

1. Introduction

This review of the literature is aimed at identifying the main types of problems that arise in the study of the behavioural adaptation induced by different driver support systems. It does not necessarily seek to be exhaustive but rather to highlight the issues to be taken into consideration before planning the experiments to be conducted during Sub-Project 1 and to identify the most relevant parameters and variables that affect driver behaviour for modelling purposes.

Given these objectives, the review of the literature was focused on systems for which a sufficient number of empirical studies was available for significant trends to be identified and discussed. Hence, two ADAS, namely ACC systems and Intelligent Speed Adaptation systems, and one IVIS, the mobile phone, were retained for in-depth examination. These systems are among the ones that have been the most intensively studied over the past 15 years.

Furthermore, in the course of preliminary discussions on the choice of systems to be studied during the next stage of the project, we found that the choices of our partners were mainly oriented towards ACC or Forward Collision Warning systems, on the one hand, and Intelligent Speed Adaptation systems, Cruise Controls and Speed Limiters, on the other (cf. Cacciabue, Macchi, Martinetto, Minutes of AIDE SP1 ISPRA Workshop, 2004). It seemed to us perfectly justified to produce a synthesis of the knowledge acquired about the behavioural effects of these systems before undertaking further research.

The following partners contributed to the writing of the report:

CIDAUT: Literature review on Mobile phone.

CERT/HIT: Examination of some questions raised by the study of long-term studies and proposition of an evaluation scheme.

INRETS: General presentation of behavioural adaptation issues and literature review of Adaptive Cruise Control systems (ACC).

JRC: Literature review on consequences of automation in aviation.

PSA: Literature review on metrics and target values to study and assess driving behaviour.

VTI: Literature review on Intelligent Speed Adaptation systems (ISA).

The report is structured as follows:

The first chapter proposes a synthesis of the main types of problems concerning the study of behavioural adaptation induced by the different driver support systems.

The next four chapters are devoted to a synthesis of studies on two main types of Advanced Driver Assistance System, ADAS (ISA, ACC) and on the mobile phone use, and to a more general examination of the consequences of automation in another area of transport research – aviation.

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Lastly, the seventh chapter proposes an evaluation scheme for studying long-term effects in driving behaviour.

A series of annexes organised in function of the systems studied contains a detailed summary of the different research studies that were analysed in depth.

This review of the literature will obviously have to be updated throughout the duration of the project in order to take account of the publication of research papers and reports covering subjects of interest to our research work. This updating of current knowledge will be undertaken within the presentation of each study of specific support systems carried out by the different partners involved in Tasks 1.2.2 and 1.2.3. At the end of the project, an updated synthesis could subsequently be integrated in the AIDE final report.

2 Behavioural adaptations to new driver support systems: a synthesis

Over the past 15 years major technological changes have taken place in the field of automobile driving. Many Research and Development programmes (in Europe, USA and Japan) have been devoted to the design and assessment of new driver support systems (for route planning, obstacle detection, car-following situations, speed control, and so on).

The development of these new systems raises crucial questions at a technical level as well as in terms of their consequences on driver activity (for a general overview, see Michon, 1993; Parkes and Franzen, 1993; Noy, 1997).

Some of these questions deal in particular with the conditions of use of these new systems, their effects on driver behaviour and strategies, and their impact on the functioning of the traffic system (traffic, safety).

Numerous processes may in fact come into play between the introduction of a technological innovation, its “adoption” by drivers, its “translation” into behaviour (whether “safe” or “risky”) and its longer-term consequences on the functioning of the traffic system (Brown, 1985).

These processes must therefore be thoroughly investigated, in particular those accounting for drivers’ interactions with the driving environment.

2.1 Behavioural Changes

These new systems will mediate drivers' interactions with their driving environment (vehicle, road infrastructure, other road users) by creating new sources of information and/or offering new modes of action regulation. They will thus alter the conditions in which the driving task is currently performed and, as a result, changes in drivers’ activities can be expected. Those changes may occur:

- Within the very activity of “assisted” drivers (in terms of divided attention between the new internal sources of information and direct monitoring of the road environment, changes of driving strategies, delegation of control to the driver support system, etc.);
- Within the interactions between “assisted” drivers and other road users (effect on the behaviour of other road users, “readability” of assisted drivers' behaviour for other drivers, and so on);
- And, as a result those changes may have an impact at the general level of traffic conditions (speed, stability of traffic flow, etc.).

It is then important to specify the nature, direction and extent of the changes likely to occur at these different levels, since these changes will determine the ultimate impact on road safety (Evans, 1985; OECD, 1990).

2.2 Behavioural adaptation in road safety research

In road safety research, the term “behavioural adaptation” is mainly used to signal unexpected or unanticipated behavioural changes that appear in response to the introduction of a change in the traffic system and which may (more or less) jeopardise its expected safety benefits. Thus, the emphasis is primarily put on the *negative aspects* of the phenomenon. Behavioural adaptation may be an immediate response to the change introduced in the traffic system or may only appear after a long time period.

An OECD expert group (1990) defines behavioural adaptation as “those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change”. On the basis of a review of a large number of empirical studies, the expert group concluded that “…behavioural adaptation to road safety programmes does occur although not consistently”. The magnitude and direction of its effect could not be precisely stated. The reviewed studies suggested that behavioural adaptation generally did not eliminate safety gains from measures, but tended to reduce the size of the expected effects.

Behavioural adaptation may appear in many different driving tasks: in change of speed, change of following distance, way and frequency of overtaking, way and frequency of lane changing, late braking, change of level of attention, etc. (Draskóczy, 1994). In hypothesising and testing behavioural adaptation it is important to take into consideration the fact that it is an effect that may not appear immediately when the driving context is changed, but usually appears only after a familiarization period.

Although behavioural adaptation is a widely acknowledged phenomenon, the factors likely to explain it and the processes underlying its occurrence (in time and space) are not clearly established.

Various driver models, such as models of drivers’ risk control, are often referred to when studying behavioural adaptation (for a discussion of these models see for instance Saad, 1989; Ranney, 1994). These models emphasise the role of several psychological processes (cognitive and motivational), which may induce the occurrence of a behavioural response and influence its direction and magnitude.

In line with these models, several variables have been suggested as factors likely to induce the occurrence of a behavioural response, such as :

- the drivers’ perception of the change introduced in the traffic system : does the change directly influence the way the driving task is performed, does the change alter the drivers’ subjective safety ?
- the degree of freedom that the change allows drivers : is there any opportunity for drivers to change their behaviour ?
- the presence of competitive motives for changing behaviour, and so on (OECD, 1990).

As mentioned above, most debates and research works have been devoted to an analysis of the negative aspects of behavioural changes. When analysing the impact of new support systems, we choose to adopt a broader definition of adaptation that is rather more classical in psychological terms with reference to Piaget’s work: “The whole set of behaviour changes that are designed to ensure a balance in relations between the (human) organism and his surroundings, and at the same time the mechanisms and processes that underlie this phenomenon" "Adaptation processes come into play each time a situation embodies one or several new, unknown or simply unfamiliar elements. These processes are said to be assimilating when they integrate the new data into previously established patterns of behaviour, and accommodating when the new data transform an existing pattern or schema in such a way as to make it compatible with the situation" (Grand Dictionnaire de la Psychologie).

Adopting such a definition means that the scope of investigation should incorporate any potentially relevant behavioural changes associated with the use of the new support systems, examine the process (cognitive as well as motivational) underlying the behavioural changes observed and enable us to find out how they evolve through training and experience.

2.3 Studying Behavioural adaptation

The changes associated with the use of these new support systems and their acceptance by drivers will depend on:

- the types of tasks they are designed to support, (navigational, guidance or control tasks, Allen et al., 1971);
- their functions and the type of mediation they provide ("description" as regards the state of the environment, "prescription" as regards the regulating action to take; " intervention " in the event of driver failure or his deliberate delegation).

Up to now, most support systems are dedicated to specific driving tasks. Their competence is by definition limited to the area of that task. The mediation offered is thus only partial, the driver's direct control over the road environment is always necessary and he remains responsible for the overall management of his journey.

Therefore, studying the integration of these new systems in the overall driving activity is essential.

Studying the integration of a new aid into driving activity and identifying behavioural changes entails (Saad and Villame, 1999):

- Taking account of the essential dimensions of the road environment in which that activity takes place (nature of the interactions at work, regulatory, structural and dynamic constraints, etc.). This reference to the context (Suchman, 1987) is particularly important in view of the diversity and variability of the road situations that drivers may encounter during a journey.
- Choosing functional units of analysis making it possible to examine not only the aid's impact on the performance of the specific task to which it is dedicated (compliance with safety margins or speed limits, for instance), but also its compatibility with the performance of other driving tasks (overtaking manoeuvres, interactions with other users, and so on).
- Selecting the relevant indicators for revealing the changes likely to take place in driver's activity.

These issues make direct demands on knowledge of the driving task and of the psychological mechanisms that govern drivers' activity.

Many research studies have been carried out, focusing on the impact of various individual support systems such as Collision Avoidance System (CAS), Speed Limiters or Adaptive Cruise Control, either in the controlled context of driving simulator and/or in the complexity of real driving situations. Most of these research studies have been short or medium term studies and "the effects of the support systems on traffic safety and driver behaviour are still uncertain in many respects" (Nilsson et al., 2002), especially long term effects. Nevertheless some critical issues have already been identified. They are described and discussed below.

2.3.1 The diversity of behavioural changes

The first critical issue encountered when examining the impact of a given support system concerns the diversity of behavioural changes studied and observed as well as the magnitude and direction of these changes.

For example, the main behavioural changes observed when studying the impact of an Adaptive Cruise Control (ACC) are changes in speed, in the safety margins (time headway or time-to-collision) adopted in various car-following situations (such as steady car-following, catching up a slower vehicle, etc.) , and in the lateral control of the vehicle, as well as changes in lane occupancy and in the frequency of lane change manoeuvres. Furthermore, the *results obtained are sometimes contradictory*: in some studies, the driving speed increases when using ACC (Ward et al., 1995; Hoedemaeker and Brookhuis, 1998) whereas in others this is not the case (Stanton et al., 1997; Törnos et al., 2002) ; the same results are observed for the frequency of unsafe safety margins adopted when using ACC as well as for the lateral position of the vehicle. *Sometimes the results are similar*, as in the case of the lane occupancy on motorways (Hoedemaeker and Brookhuis, 1998; Nilsson, 1995; Saad and Villame, 1996).

The same tendencies were observed when studying the behavioural impact of Intelligent Speed Adaptation systems (ISA). Changes in car-following behaviour were observed when driving with ISA and the direction and magnitude of these changes varies according the studies. For instance, Persson et al. (1993) Carsten and Comte (1997), Várhelyi and Mäkinen (2001), Hjälmdahl and Várhelyi (2004) found that, when driving with ISA in urban areas, the time headway in car-following situations increased. The changes were small but still on the positive side from a traffic safety point of view. On the other hand, Carsten and Fowkes (2000) came to the conclusion that safety-critical close following (less than 1 second) increased, both on urban and rural roads. Várhelyi and Mäkinen (2001) also found that the following distance was reduced on rural roads when driving with the system.

Part of the observed diversity may be due to *the functional characteristics of the support system* studied (for instance for ACC system, control algorithm, selected target time headway, deceleration level used, etc.). Some studies, comparing the effect of different characteristics of ACC (for instance the level of deceleration afforded by the system), suggest that these differences may influence driver behaviour with respect to learning and/or mental workload for instance (Kopf and Nirschl, 1997; Hoedemaeker and Kopf, 2001; Törnros et al.1992).

The diversity of the results obtained also raises questions about the *methods used,* the *type* and *number of variables* selected for assessing the impact of the system, and finally the *(implicit or explicit) models governing their choice*.

When comparing the results, particular attention should be paid to these methodological issues. The context in which the studies have been carried out (driving simulator, closed tracks or real driving situations) should be specified as well as the various scenarios and driving tasks in which the behavioural changes have been identified. In the same way, the duration of exposure to assisted driving should be taken into account. The diversity of the results obtained could then be examined and discussed in the light of the characteristics of these various contexts and scenarios.

This kind of analysis is particularly relevant if we consider that the situational context plays an important role in the behavioural changes observed when driving with a support system, and more generally in driver's activity.

2.3.2 The importance of the situational context and the collective dimension of driving

Many systems are designed to support drivers in maintaining some safety thresholds or ensuring compliance with some formal driving rules (such as maintaining safe time headways in car-following situations or adhering to legal speed limits), independently of the characteristics of road situations (infrastructure and traffic related) and the task being performed or planned, which determine the driver's current regulating actions (Saad, 2002).

Several studies reveal the influence of the overall traffic conditions and of the characteristics of the road infrastructure on the decision to use the support systems (decision to engage an ACC system, for instance, Fancher et al., 1998; or to follow the "advices" of a Anti-Collision system, Malaterre and Saad, 1986) as well as on the magnitude of the behavioural changes observed when using them (for instance, increase of safety margins before overtaking only in light traffic conditions when using a system providing a time headway feedback, Fairclough et al. 1997 or when using an ACC, Saad and Villame, 1996).

These studies show that drivers' use and acceptance of these systems closely depends on the way they integrated formal rules in their driving and the tolerances they deem admissible, according to the situational context (infrastructure and or traffic related) and the task to be carried out.

Drivers' use and acceptance of the assistance provided also depend on its impact on the way they usually interact with other drivers (on the basis of more or less informal rules or behavioural norms, Saad et al., 1999). In many interaction situations, such as driving in dense or unstable traffic conditions, drivers are reluctant to use the systems when doing so would require a significant deviation from their usual strategies.

For example, in a field trial with a « driver select » ISA system (where the driver has the option of whether or not to engage the ISA system), Carsten and Fowkes (2000) observed that drivers were prone to disengage the system at locations where speeding was the *norm for the surrounding traffi*c. In such driving situations, drivers prefer to be in control of their speed and turned the system off when they felt vulnerable or under pressure form other drivers.

Furthermore, drivers are concerned about the way other drivers might interpret their own behaviour. Some critical reactions of other drivers (close-following behind, cutting-in manoeuvres, flashing headlights, etc.) are perceived as a *negative feedback* and often lead them to give up the use of the support system or to ignore its recommendation (Saad and Malaterre, 1982). Using a support system not only has an impact on the behaviour of the "assisted" driver but also on other (unaided) users' perceptions and understanding of his behaviour when they interact with him.

Other studies have shown that driving with an ISA system may have an influence on the driver's interaction with other road-users, either negative or positive in the short term, but likely to improve after longer experience with the system. For instance, Persson et al. (1993) found that there was a slight increase of incorrect behaviour towards other road-users at junctions when driving with a mandatory intervention system. Almqvist and Nygård (1997) found an improved interaction with unprotected road users such as improved stopping for pedestrians. Hjälmdahl and Várhelyi (2004) found after long-term use of ISA that drivers' give way behaviour at junctions was improved.

To sum up, these studies highlight the circumstantial requirements of driving assistance according to the dynamics of various environmental conditions and to the drivers' motives, objectives and intentions in these conditions.

They also confirm the need to adopt a multi level approach when assessing behavioural adaptation to new driver support system, that is to say studying possible changes within the activity of "assisted" drivers as well as within their interactions with other road users.

2.3.3 The diversity of drivers' interaction modes with a support system

As far as we know, very few studies have examined in detail the way drivers interact with a new support system. However, such an analysis should provide useful information for understanding *how the drivers share and learn to share the control of their driving with a new support system*.

The results of some studies dealing with an in-depth analysis of drivers' interactions with an ACC system emphasize the great diversity of interaction modes used by drivers :

- in terms of ACC engagement (mainly depending on the type of road, the speed level and the traffic density) as well as in terms of the overall duration of ACC engagement (associated with the age of the drivers and with their "driving styles", Fancher et al., 1998) ;
- in terms of the drivers' use of commands for setting and adjusting the set speed values and in terms of driver's "taking over actions" (direct intervention on the accelerator or the brake). The situational context as well as the characteristics of

> the drivers (their “driving style”) seem to play a crucial role in the way drivers interact with the driving support system (Saad et al., 2003).

We should keep in mind that these results have been obtained during short and medium term exposure to ACC driving. Part of the observed diversity may reflect the fact that drivers are still exploring the various modes available for interacting with the system. On the other hand, this diversity may also reflect the fact that drivers have acquired enough experience with ACC to be able to diversify their interaction modes, according to the various situational contexts encountered during their journeys.

Longitudinal studies are needed in order to explore these alternative hypotheses.

2.3.4 The differential impact of driver support systems

Another critical issue when studying behavioural adaptation is related to the potential differential impact of the support systems.

Because of the great diversity of the driver population (both in terms of car usage and individual characteristics), many driver characteristics may be considered relevant for dealing with this issue, such as driver’s age and gender, degree of experience and practice, but also personality traits such as “Sensation Seeking” or “Locus of Control”.

The choice of a set of individual characteristics to take into account mainly depends on the objectives of the research and the process under investigation.

Driving style

In some studies, the concept of “driving style” has received particular attention. It is not in the scope of this short presentation to discuss neither the various dimensions characterising the “driving style” nor the different behavioural indicators used to render this variable operational (for more information see, Hoedemaeker, 1996; French, West, Elander and Wilding, 1993).

Basically, the “driving style” is described as a relatively stable characteristic of the driver, which typifies his/her personal way of driving, the way he/she chooses to drive (for instance, the level of speed or the safety margins more frequently adopted, the general level of attention devoted to the driving task and so on).

Several studies have taken into account this variable when studying the impact of an ACC system, either by design (the participants were selected on the basis of a Driving Style Questionnaire by Hoedemaeker and Brookhuis, 1998.) or a posteriori, on the basis of the identification of some manifest behaviour patterns (such as the driver’s propensity to change lane frequently on the motorway, by Saad and Villame, 1996 or the driver’s tendency to drive faster or slower than the surrounding traffic and to adopt short time headway in car-following situations, by Fancher et al., 1998).

The results suggest that the various dimensions of the driving style taken into account in these studies may play an important role in the use and acceptance of new driver support systems and in the occurrence of behavioural changes when using them.

For example, some behavioural changes associated with the use of ACC, such as a reduction in the number of lane change manoeuvres and a higher rate of left-lane occupancy, are primarily observed within the group of drivers who usually tend to change lane frequently when driving on motorways while no significant changes were observed for the other « rather less mobile » group, Saad and Villame, op.cit.). Driving style is also referred to by Fancher et al. (1998) to account for the differences in the overall use of ACC observed in a rather extensive field study. In particular drivers qualified as « hunter/Tailgater », because of their fast driving and their propensity to adopt short time headways, used the ACC system less often than the other groups. Hoedemaeker and Brookhuis (1998) also identified some changes related to the (self reported) driving styles, depending on the variable taken into consideration. For instance, while all drivers increase their driving speed, irrespective of their driving style, in some scenario (here a situation where the drivers have to brake in response to the full stop of a lead vehicle) the results indicated that low speed drivers increased their braking when driving with ACC while "high speed" drivers braked as hard as when driving without ACC. Differences in driving styles have also an effect on drivers' acceptance of the assistance provided: "high speed" drivers are less positive about ACC than "low speed" drivers.

To sum up, "driving style" seems to play a role in the overall frequency of support system usage, the magnitude of some behavioural changes when using the system as well as in the level of acceptance of the assistance provided.

Personality traits: locus of control and sensation seeking

Several authors (see Brown, 2000; Jonah et al., 2001; Rudin-Brown and Noy, 2002; Rudin-Brown, 2004, Stanton and Marsden, 1998, Stanton and Young, 2000; Ward et al., 1995) have put the emphasis on some general personality traits, such as "Sensation Seeking" and "Locus of Control".

These personality traits are assumed to, more or less directly, influence the occurrence of behavioural adaptation either through a general tendency for risk compensation (for "High sensation seekers") or a propensity to manifest over-reliance in automation (for "External LOC").

Ward et al. (1995) and, more recently Rudin-Brown and Parker (2004) took into account these variables when studying the behavioural impact of an ACC system. Their results suggest that the *magnitude* of behavioural changes observed when driving with ACC was sometimes more important for these categories of drivers. They also found differences in the drivers' subjective assessments of the impact of ACC on their driving.

For example, Ward et al. (op.cit.) found that high sensation seekers drove faster than low sensation seekers with ACC. High sensation seekers also perceived the ACC system to increase safety more than low sensation seekers and reported lower levels of arousal and effort when driving with ACC.

Rudin-Brown and Parker (op.cit.) observed the same tendencies. All drivers reacted more slowly to the activation of the brake lights of a lead vehicle, but this effect was particularly pronounced in high sensation seekers. Impaired lane keeping when driving with ACC was also more evident in high sensation seekers. In take-over situation, drivers with external Locus of control took longer to react than those with an internal LOC.

To sum up, some individual characteristics such as “Sensation Seeking” or “Locus of Control” seem to *amplify the behavioural changes* observed when driving with the driving support systems. It should be noted, however, that the relationship between these general individual traits and other individual characteristics like « driving style » are not quite clear and should be clarified.

2.3.5 Learning to use new driver support systems

As emphasised in section II.3, most support systems are dedicated to specific driving sub-tasks and their competence is by definition limited to the area of that sub-task. It is therefore important to know if drivers can easily learn the range and limits of the support system’s competence. This issue is of vital importance for support systems that intervene directly in vehicle control (for example, Speed limiters or ACC systems).

The learning process is certainly crucial for helping drivers to build appropriate representation of the assistance provided by the system and for “calibrating” their trust in it. Appropriate mental models of and confidence in new drivers support systems should promote their optimal (and safe) use by drivers (see for example, Muir, 1987, 1994; Amalberti, 1996).

However, to our knowledge, it has received little attention until now (at least if we refer to public papers and reports). Some studies have indirectly dealt with this issue on the basis of drivers’ self-assessment of the ease of learning of some support system (see for example Nilsson, 1995, Fancher et al, 1998 for ACC system). Yet, the learning process itself has not been studied. Only few papers dealing directly with this issue have been identified through our bibliographical research. They are presented below.

These studies dealt essentially with the learning of ACC systems, and more particularly with learning how to use them in “take-over” situations, situations where the driver has to decide whether to regain control over his speed or not. These studies provide some useful insights on the duration and different stages of the learning process.

Kopf and Nirschl (1997) studied the learning of three versions of ACC (differing mainly in the maximum deceleration which could be applied by the system, soft, medium and hard, and the time headway set values). Each driver carried out five 130-km journeys (lasting about an hour and a quarter). The results show that drivers’ intervention frequencies and workload decrease as drivers become more experienced, thus indicating that drivers are able to learn the system behaviour. They also reveal that a different layout of ACC parameters influenced driver behaviour with respect to learning and mental workload. As a conclusion, the authors suggest that it is important to find means to accelerate the learning process, for instance by supporting drivers’ predictive activities about the ACC system behaviour.

Kopf and Simon (2001) carried out a more extensive analysis of drivers’ long-term interactions with an ACC system. Each participant drove with an ACC system for two and half weeks. Analyses were focused on changes over time of ACC usage and drivers’ intervention in take-over situations. The results indicate that ACC usage evolves through different stages: a preliminary stage of getting to know the system (learning to operate it), a testing phase (learning the system limits) and a familiarisation stage (learning to use the system appropriately in particular environments). An analysis of changes over time of drivers' intervention in take-over situations suggests that there was a trend towards testing the limits of the system at the beginning, followed by a certain apprehension of the system's capabilities and then a more personalised "steady use" of the system. As a conclusion, the authors suggest that two kinds of assistance are needed, one to help drivers develop appropriate representations of the system's behaviour and one to reduce the learning time.

Weinberger et al. (2001) conducted a long-term operational field test in order to achieve more information about the learning process for both the usage of controls and display and the judgement of take over situations. The participants used an ACC-equipped car over a period of four weeks each. The data were analysed with respect to the duration of the learning phase. Both drivers' self assessment of the length of learning and drivers' behaviour during take over situations suggest that two or three weeks are needed to learn the operation of ACC and the assessment of take over situations. However, as the participants in the study drove much more than the average driver, the authors suggest that other ACC users might need a different learning time.

More recently, Manstetten et al. (2003) emphasised the concepts of « learnability of driver assistance systems » and « self-explanatory ADAS ».

- With reference to the project RESPONSE, "a system is learnable, if accurate assimilation of information by the driver occurs, evidenced in the driver's understanding of system function, system handling and situational limits".
- A "self-explanatory" support system is defined as a "driver assistance system leaving a minimal amount of learning demand to the driver and eliminating learnability issues which can result in safety-critical traffic situations".

The authors presented a national research programme (the INVENT FVM project, "Driver behaviour and Human Machine Interaction"), which aims to develop a guideline for designing such a "self-explanatory system", minimising the need for learning. In order to achieve this aim, several empirical studies were carried out in a driving simulator to find out general "learnability" issues of ADAS. Different types of ADAS were under investigation, differing by their degree of intervention (informative or intervening systems) and which may present different learning demands. Furthermore, additional concepts promoting the ADAS learning phase are developed and evaluated throughout the project (such as those suggested above by Kopf and Simon 2001). The final guideline for the development of self-explanatory driver assistance systems is planned for the end of the INVENT project in mid 2005.

It is interesting that the issue of learning to use new support systems is gaining more attention as indicated by the projects described above as well as other projects under development (see for example, the Australian TAC Safecar project, Regan et al. 2001 where training is also considered to be of vital importance).

The research planned in the AIDE project will contribute to this effort of understanding the learning demands and its impact on behavioural adaptation.

2.4 The issue of behavioural adaptation in the AIDE project

As mentioned above, most studies of behavioural adaptations to new driver support systems have been short-term studies and focusing mainly on the use of a single support system.

Studying long term behavioural adaptations and developing an integrated management of driver support remains however a necessary and unavoidable step in defining the layout of models of driver behaviour that support the design and development of integrated tools and interfaces.

This issue is one of the major goals of the AIDE project. In particular, AIDE aims at generating knowledge and methodologies and developing human-machine interface technologies for safe and efficient integration into the driving environment of Advanced Driver Assistance Systems (ADAS) and In-vehicle Information Systems (IVIS), as well as nomad devices (such as “Personal Digital Assistants” –PDA- or “Communicators”).

The planning of the research activity with respect to the issue of behavioural adaptation deals firstly with the problem of the *circumstantial* and *temporal* management of the assistance provided by various systems in the driving process.

With respect to the *circumstantial* conditions that affect processes of behavioural change, the following aspects will be studied:

- The nature and extent of behavioural changes associated with the use of individual driver support systems;
- The conditions in which these changes take place;
- The “reasons” why these changes occur;
- The characteristics of the drivers more likely to present these behavioural changes.

It will entail in particular: 1) gauging the occurrence, nature and magnitude of the behavioural changes as a function of the type of support system being studied (informative, prescriptive or intervening system); 2) then examining to what extent these changes are observed in relation to analogous driving situations or tasks and/or in relation to drivers’ common characteristics.

With respect to the *temporal* factors affecting behavioural adaptation, the variables will be organised according to specific phases for long-term effects. In particular, two main phases will be considered, namely:

- *Learning phase*: the driver discovers the system, learns how it operates, identifies the precise limits of its competence and delimits its domains of utility. This learning process is assumed to be crucial for the driver representation of the system, the confidence he/she has (and ought to have) in it and its optimal use. This learning process depends on the way the system is presented to the driver (instruction for use, as well as information provided on-line), the driver level of experience and familiarisation with new technologies.

- *Integration phase*: the driver, through experience using the system in different road situations, reorganises his/her activity by integrating the system in the management of the overall driving task.

It will involve examining whether, when and how behaviour associated with the use of support systems changes with training and experience. In that regard, it has to be pointed out that, because of the scarcity of research carried out into the learning process and the long-term effects, it is hard to determine the temporal span of the different phases distinguished above. Different support systems will probably require different learning times. The research planned in the AIDE project will be developed in such a way as to optimise the opportunities for identifying the main "stabilisation phases" of the learning and integration process for different support systems.

This process will lead to the identification of the relevant variables to be used to assess behavioural adaptation effects. The correlation between these variables and adequate taxonomies and classification of road situations and driving tasks (scenarios of dynamic situation) will be devised in order to associate the variables with realistic conditions.

In this way it will be possible to plan and carry out a number of experimental and field evaluations that will enable to develop and consolidate a model of driver behaviour that can act as reference for the design of an adaptive-integrated in vehicle interface supporting the multiple tasks of drivers in modern vehicles.

3 Intelligent speed adaptation systems

3.1 Introduction

The strong relationship between the speed level and accidents has been shown in several studies; small speed level changes result in significant changes in the number of accidents (see e.g. Salusjärvi, 1981; Elvik, Vaa and Östvik, 1989; Finch, Kompfner, Lockwood and Maycock, 1994; Nilsson, 2004). An additional finding is that lower speed variance is correlated with fewer accidents (see e.g. Salusjärvi, 1981; Finch et al., 1994; O'Cinnéide and Murphy, 1994). These observations indicate that lower and more even speeds effectively reduce the number of accidents and mitigate the outcome of collisions. However, compliance with speed limits is low, for example, a survey of actual speed levels in Europe (Draskóczy and Mocsári, 1997) showed that speeding is a common phenomenon, especially widespread on urban roads and motorways. So far, speed management has typically been concentrated on the road and its environment (engineering), and on the driver (e.g. enforcement). Engineering measures such as traffic calming have proved to be effective in reducing speed at isolated sites, but the effects are localised in time and space (for an overview see Comte, Várhelyi and Santos, 1997). Visible enforcement at specified sites, directed towards certain groups of drivers and administered regularly at times when many of the passing drivers are commuters, usually results in an immediate speed reduction. Still, the extent of speed reduction in time and space is very small (see e.g. Hauer, Ahlin and Bowser, 1982; Østvik and Elvik, 1990; Teed, Lund and Knoblauch, 1993).

Recent technological advances in information and communications technology offer a much greater flexibility and a broader possibility of influencing speed. Equipment in the road environment or the vehicle itself may provide the driver with information on prevailing speed limits or speed limits in critical conditions or warn him of speed errors or register inappropriate speed or prevent the driver from exceeding the prevailing speed limit.

3.2 System definition

In-vehicle systems for speed management in various forms have been studied for over twenty years and the HMI solutions have differed over the years as has the terminology describing the various systems.

A consensus of the terminology for the various systems has however been developed over the last couple of years, mainly due to cooperation in European projects and international exchange between researchers within this field. The systems are commonly known as ISA (Intelligent Speed Adaptation) although some use the term ISM (Intelligent Speed Management) instead.

Three main types of ISA systems can be identified, and they are separated by their level of influence on the driver. Carsten and Fowkes (2000) define the three types of systems as advisory (in-vehicle information regarding the current speed limit), advisory intervention (information is given to the driver when the speed limit is exceeded by haptic or audible information) and mandatory intervention (the speed of the vehicle is physically limited to the speed limit).

In addition they differ between speed limit systems: fixed system where the speed limit is set to the legal maximum speed for each stretch of road, variable system in which local speed limits may be set to account for poor road geometry and the like and a dynamic system where the legal maximum speed can be changed to account for changing road surface, weather and visibility.

An estimation of the safety effect of ISA systems varies from a 10 percent reduction of injury accidents for an advisory intervention system up to 40 percent for a limiting system that limits the speed dynamically (Várhelyi 1996; Carsten and Comte, 1997; Carsten and Fowkes, 2000). The safety effect can mainly be attributed to the reduction in speed but behavioural adaptation which is believed to have a positive impact has been identified, there are however signs of negative behavioural modification as well.

3.3 Behavioural adaptation and ISA

(From Hjälmdahl and Várhelyi, 2004) When it comes to the phenomenon of "behavioural adaptation", an OECD scientific expert group was set up in 1990 (OECD, 1990) to examine the empirical evidence for its "existence". Behavioural adaptation was then defined as "those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change". On the basis of a review of a large number of empirical studies, the expert group concluded that "…behavioural adaptation to road safety programmes does occur although not consistently". It was stated that the magnitude and direction of its effect could not be precisely stated. The reviewed studies suggested that behavioural adaptation generally did not eliminate safety gains from measures, but tended to reduce the size of the expected effects. Behavioural adaptation can, in practice, appear in many different driving manoeuvres: in change of speed, change of following distance, way and frequency of overtaking, way and frequency of lane changing, late braking, change of level of attention, etc. (Draskóczy, 1994). In hypothesising and testing behavioural adaptation it is important to take into consideration the fact that it is an effect that does not appear immediately when the driving context is changed, but usually appears only after a familiarization period (ibid).

Mechanisms that can lead to behavioural adaptation with regard to a system like an intelligent accelerator pedal are "delegation of responsibility", "behaviour diffusion", and "compensatory behaviour". Carsten (1993) describes "delegation of responsibility" as follows: "Studies had shown that in situations people consider uncontrollable, they want to know who is 'responsible' for certain events. If other, generally more powerful, people assume responsibility, it is not unusual to delegate responsibility to them. This delegation of responsibility can lead to behaviour which is potentially more risky, e.g. in emergency situations where those at risk should make their own decisions". In the case of vehicle-based systems for driver support the driver might delegate the responsibility to the system. A driver supported by an intelligent accelerator pedal is able to devote more attention to the other driving tasks. On the other hand he might become over-reliant on the system. For example, the driver might consider that the system will always know what the speed limit is and will always issue a warning at inappropriate speeds. "Behaviour diffusion" might occur in situations where drivers are not supported by the system, e.g. when driving outside the areas covered by the system, driving non-equipped vehicles or when the system fails (Carsten, 1994). In these cases drivers who become totally reliant on the system might have difficulty in following the changes in the actual speed limits. The notion of "compensatory behaviour" has its origin in the "risk compensation" theory of Wilde (1994) (the notion that road users will use up some of the margin afforded by safety improvements by, for example, driving faster) and the "risk homeostasis" theory of Wilde (1994) (the notion that road users seek to keep their risk constant).

3.4 Results

Most of the trials carried out have been rather short in time and it is reasonable to assume that the drivers are not fully accustomed to the systems at the end of the trials and possible long term effects and behavioural modifications may not have been revealed. There are a few exceptions though where behaviour has been studied on longer term. The longest exposure to the system that has been tested is two years, but the majority of the drivers in that trial "only" drove for 6 – 11 months.

There are some conflicting results from the various studies and this is probably due to the difference in exposure and the lack of long-term adaptation. Most of the trials have also been rather small in size so it has been difficult to trace back results based on different groups of drivers and drivers with different attitudes to speed and traffic safety although there are exceptions here as well.

All of the studies have focused on speed as a primary measure and it is not surprising that speed is changed when driving with the system since that is what it is designed for. The change in speed is somewhat different depending on what road type is studied and what system is tested**.** As a rule of thumb, one can conclude that the more intrusive the system is, the higher the speed reducing effect. For instance, limiting systems have been shown to be very effective since there are no speeds above the speed limit when driving with the system, examples can be found in Almqvist and Nygård (1997), Carsten and Comte (1997), Carsten and Fowkes (2000), Várhelyi and Mäkinen (2001) and Duynstee (2001). Advisory systems have also shown to be rather effective even though there are still some speeds above the speed limit, see Vägverket (2002) on the effectiveness of a system with auditory feedback and a system with haptic feedback. No proper comparison has been carried out between the two systems but it looks like the haptic feedback was shown to be somewhat more efficient than the auditory feedback.

In Hjälmdahl (2004) the haptic system was analysed further, and he found that the advisory system was less effective for drivers with a negative attitude towards the system (i.e. drivers that experienced the system as punishment rather than support). This effect however was only discovered after long-term use. He also found that the negative (and faster) drivers experienced more stress when using the system while drivers with a positive attitude towards the system (the slower drivers) experienced driving as less stressful with the system. Informative systems (information on the speed limit but no feed back) have shown to have very little effect on speed, see Nilsson and Berlin (1992) were no effect on speed could be found of.

As mentioned above speed is the primary behaviour variable investigated followed by attitude and acceptance. There are, however, a few studies that have studied other forms of behaviour as well. These studies have revealed a couple of changes in driver behaviour that can be considered as behavioural adaptation. The most apparent one is changes in car following behaviour where Persson et al. (1993) (in-car observations), Carsten and Comte (1997) (simulator), Várhelyi and Mäkinen (2001) (instrumented vehicle) and Hjälmdahl and Várhelyi (2004) (in-car observations) found that the time headway increased when driving with the system in urban areas. The changes were small but still on the positive side from a traffic safety point of view. Carsten and Fowkes (2000) (simulator) on the other hand came to the conclusion that safety-critical close following (less than 1 second) increased, both on urban and rural roads. Várhelyi and Mäkinen (2001) also found that the following distance was reduced on rural roads when driving with the system. The study of Hjälmdahl and Várhelyi (2004) observed long-term effects while the other studies varied from a without / with test drive up to two months exposure.

The various ISA-systems studied were also shown to have an influence on the driver's interaction with other road-users. Persson et al. (1993) found that there was a slight increase in incorrect behaviour towards other road-users at junctions when driving with a mandatory intervention system. Carsten and Comte (1997) found in a simulator study that driver behaviour improved when the speed was limited although a riskier gap acceptance was detected. Carsten and Fowkes (2000) also found, in a simulator study, that drivers accepted shorter gaps when yielding and they drove with a reduced minimum time to collision. They also found that the drivers were less likely to be involved in critical situations and conflicts with the system engaged. In conclusion they also stressed the importance of observing behaviour after long-term use. Hjälmdahl and Várhelyi (2004) used an in car observation method to study driver behaviour after long-term use of and they found that drivers give way behaviour at junctions was improved after long-term use of the system. They studied correct and incorrect yielding and found that the percentage of correct yielding increased.

Almqvist and Nygård (1997) used an in-car observation method to study driver behaviour and they found an improved interaction with unprotected road users such as improved stopping for pedestrians. Hjälmdahl and Várhelyi (2004) also used in car observations to study driver behaviour and they too found that drivers' give way behaviour was improved after long-term use of the system, they studied yielding behaviour with regard to early yielding, late yielding, not yielding at all etc.

Some of the results that have been found are rather contradictory, for instance Persson et al. (1993) found that drivers had a higher speeds in corners when driving with the system while Várhelyi and Mäkinen (2001) found a smoother approach speed at junctions. In Várhelyi et al. (2004), where the long-term effects are studied, no effect on speed could be found neither in approaches to junctions nor in corners.

Some of the studies have found signs of delegation of responsibility, i.e. putting too much trust in the system. Comte and Jamson (1998) found in a simulator study that drivers using a mandatory ISA were actually driving faster in critical conditions such as slippery roads and fog than without any support system. The system that showed to be the most effective in critical conditions was a dynamic system, i.e. a system that lowers the speed in critical conditions. Hjälmdahl and Várhelyi (2004) also found some tendencies to delegation of responsibility, among others, they discovered that on locations where the drivers were not supported by the system, they sometimes forgot to change their speed when the speed limit changed. They also found that drivers occasionally did not adapt their speed to the prevailing traffic conditions as well as they did without the system. Both these findings from Hjälmdahl and Várhelyi (2004) were not statistically significant and they concluded that further research was needed.

There are various explanations to why ISA has affected behaviour in certain ways but the positive behavioural changes are usually attributed to slower speed which means more time to interact with other road users. It is also attributed to a more relaxed and calmer driving style. Slow speeds also make stopping and yielding easier. Negative behavioural changes are usually attributed to increased stress due to the system or drivers trying to compensate for lost time.

3.5 Further research

Most of the studies that have investigated behavioural changes have concluded that more research is needed, especially on behaviour after long-term use of the system. The importance of comparing various systems' effects on behaviour and effects on various driver types has also been stressed. Some studies have seen signs on compensatory behaviour and also signs of automation but there is no definite evidence of theses effects. In Hjälmdahl (2004) it is discussed whether these effects may differ depending on one's attitude towards the system.

Another area that is proposed for further research is dynamic speed adaptation and how a system can be designed to give the driver so much support, without taking him/her out of the vehicle control loop.

4. Adaptive cruise control systems

4.1 Introduction

Adaptive Cruise Control (ACC) or Intelligent Cruise Control (ICC) system use sensor to detect the presence of a preceding vehicle and to determine its distance and speed (generally within a maximum detection distance of 150m). If a preceding vehicle is detected, the speed of the ACC-equipped vehicle is adjusted to maintain a pre-set distance or time headway. In most ACC systems, the driver has a choice between two or three headway target values. If no preceding vehicle is detected, the ACC keeps a pre-set speed (selected by the driver) and functions as a traditional cruise control. The driver can resume control at any time.

ACC systems are primarily designed as comfort enhancing systems, and only limited level of deceleration may be used to adjust the speed of the vehicle in car-following situations. Thus ACC systems are not designed to handle emergency braking situations and the driver has to resume control in critical situations. Furthermore, ACC systems do not deal with stopped vehicles, neither have a STOP & GO functionality.

Thus, while ACC affords assistance in the control of speed and distance headway in many current highway/motorway forward driving conditions, the driver remains responsible for the overall safety of the driving task and has to supervise "road events" (traffic and infrastructure related) along his journey as well as the functioning of the ACC system.

The major concerns in most research on behavioural changes likely to be associated with the use of ACC were:

- Reduction in driver's workload likely to induce reduced attention to the driving task;
- Drivers' ability to cope with ACC limitations and to resume control in critical traffic scenarios;
- Driver acceptance of the ACC system.

4.2 Main characteristics of the studies carried out

Most of the research carried out has dealt with short or medium term effects. To our knowledge, the maximum duration of ACC driving was limited to four consecutive weeks (Fancher et al., 1998; Weinberger et al. 2001).

The *methods* used for studying behavioural changes associated with the use of ACC systems generally combines measurement of driver behaviour and driving performance (sometimes performance in a secondary task is also measured) and drivers' self assessment of mental workload, drivers' attitude towards and acceptance of the ACC systems. The studies were carried out either in the controlled context of a driving simulator (fixed or moving base) or in the complexity of real driving conditions. Some studies focused on the impact of a given ACC system, while the others compared behavioural changes with respect to various types of ACC systems.

Behavioural changes were identified on the basis of several types of indicators, such as the speed, lateral position and safety margins in car-following situations (time headway or time to collision) as well as lane occupancy and frequency of lane change manoeuvres. *Workload* was assessed either on the basis of drivers' self-assessment on various scales (most often the NASA-TLX scale) or measured on the basis of drivers' performance in a secondary task. *Drivers' opinions and acceptance* were assessed on the basis of questionnaires and interviews.

Behavioural changes were examined either at a global level (average speed on the overall driving trial for instance) or in some specific driving scenarios or tasks to be carried out (approaching a slower vehicle or stationary queue, stable car-following situations, overtaking a slower vehicle, for example).

Driving with ACC was mainly studied *on motorways*. In some cases, ACC driving took place also on other types of rural roads. The traffic conditions were taken into account in some studies. In a large field study (Fancher et al., 1998), ACC driving took place in more diverse road environment (including driving in urban area) and traffic conditions.

Finally, the majority of the studies were carried out *with experienced drivers in the middle age* (between 25 years old and 60 years old) and both genders were usually represented. In some studies, drivers have a preliminary experience with conventional Cruise Control (Fancher et al, 1998). In general, there were no novice drivers involved in the studies.

The *main behavioural changes* observed when studying the impact of an Adaptive Cruise Control (ACC) are changes in speed, in the safety margins (time headway or time-to-collision) adopted in various car-following situations (steady car-following, catching up a slower vehicle, etc.), and in the lateral control of the vehicle, as well as changes in lane occupancy and in the frequency of lane change manoeuvres.

The results obtained are more or less convergent and, as emphasised by Nilsson et al. (2002) "the effects (...) on traffic safety and driver behaviour are still uncertain in many respects"

4.3 Main results

4.3.1 Behavioural changes: some overall tendencies

Driving speed and Time Headway

Driving speed and safety margins in car-following situations (distance or time headway) are generally considered as basic indicators for characterising efficiency and safety of the driving task.

In some studies, the driving speed increased when driving with ACC (Ward et al., 1995; Hoedemaeker and Brookhuis, 1998) whereas in other cases speed did not change (Stanton, 1997; Saad and Villame, 1996) or decreased when driving with ACC (Hoedemaeker & Kopf, 2001; Törnros et al., 2002). In general, speed variability is reduced when driving with the ACC system.

The same tendencies were observed for the time headway adopted when using ACC compared to manual driving. For example, Fancher et al. (1998), Saad and Villame (1996) observed that the use of ACC reduced the frequency of short time headway, Stanton et al (1997) and Hoedemaeker and Kopf (2001) found no differences between manual and ACC driving and Ward et al. (1995) found a tendency to drive with shorter TH with ACC. It should be noted that the use of ACC seems to reduce differences between drivers with respect to time headway. (Hoedemaeker and Brookhuis, op.cit.; Saad and Villame, op.cit.).

Distance or Time headway when changing lane

Törnos et al. (2002) examined the distance headway when overtaking in five scenarios on motorways and found no significant differences for any of the scenarios between manual and ACC driving.

Saad and Villame (1996) studied the time Headway (N= 453 manoeuvres) for pulling out (the driver change lane from a fast lane toward a slower one) and pulling in manoeuvres (the driver change lane from a slow lane toward a faster one). Overall, time headways were significantly greater when driving with ACC. However, these changes depend on the *type* of *manoeuvre performed and of traffic density*. When driving with ACC, drivers adopted larger headways when pulling out (before overtaking) whereas the difference was not significant when pulling in. Furthermore, time headways in average-density traffic increased significantly when driving with ACC, whereas that was not the case when the traffic constraint is stronger.

Lateral position

The control of the lateral position of the vehicle on the road is assumed to indicate a reduced attention to the driving task. The results are also contradictory and the behavioural changes uncertain. While Hoedemaeker and Brookhuis (1998), Ward et al. (1995), Rudin-Brown and Parker (2004) found an effect of ACC on the driver's control of the lateral position of the vehicle, Stanton (1997) and Tornos et al (2002) found no changes in the drivers' lateral control performance.

Lane occupancy

When this variable is taken into account, the results indicate the same tendency for drivers using ACC to spend more time in the left lane (Hodemaeker and Brookhuis, 1998; Nilsson, 1995; Törnros et al. 2002), associated in some case with a reduction in the number of lane change manoeuvres carried out (Saad and Villame, 1996).

4.3.2 Workload and attention

In many research works, the hypothesis was that driving with ACC may reduce drivers' workload and, as a consequence drivers might devote less attention to the driving task. Workload is usually assessed on the basis of drivers' subjective assessment (NASA TLX) or through drivers' performance to a secondary task.

As previously, some differences in results were observed.

Nilsson (1995) found no difference in subjective workload between manual driving and ACC driving (both driving conditions imposing a moderate load), while Hoedemaeker (1998) and Törnros et al. (2002) found that subjective workload is lower in supported driving. Stanton (1997) and Rudin-Brown and Parker (2004) also found that the performance to a secondary task was better when driving with ACC.

Some results suggest that workload depends on the *characteristics of the systems* under study and *the task to be carried out*.

Nilsson and Nåbo (1996) comparing the effect of two Intelligent Cruise control systems (ICC), Automatic (speed and headway was controlled automatically) and informative (advise on speed and headway was given), found that the use of informative ICC imposes higher mental demand on the drivers than the automatic ICC.

When comparing three ACC systems (one Assisting ACC, giving only feedback to the driver and, two Automatic ACC with and without braking), Hoedemaeker and Kopf (2002) found that the average subjective workload increased with the Assisting ACC but it decreased when driving in both Automatic ACC, compared to manual driving. They also studied drivers' visual attention (assessed by means of a visual occlusion technique). Overall, driving with ACC reduces visual workload, but the reduction is more important in car-following situation than in a deceleration situation.

Workload also depends on drivers' level of familiarisation with the system.

Kopf and Nirschl (1997) studied the learning of three versions of ACC (differing mainly in the maximum deceleration which could be applied by the system) and found that workload decreases as drivers become more experienced with the systems. The results also indicated that different characteristics of ACC influenced mental workload.

4.3.3 Behavioural changes in « critical » driving scenarios

Most of the results obtained came from simulator studies or closed track experiments, where by definition, such critical events can be studied without real danger for the participants. However, and for the same reason, we should keep in mind that driver risk-taking in this context may be quite different from that observed in real driving situations. This is a paradox that we usually have to deal with in traffic safety research.

Particular attention was devoted to take-over situations, where the driver must intervene, more or less rapidly, in order to ensure safety. The scenarios studied were generally associated with a change in the driving situation, which requires the driver to reduce his speed, and, in some cases to brake. In some studies, a failure of ACC was simulated, which also requires the driver to intervene.

In most research works, the hypotheses were either that when driving with ACC, driver attention to the driving task may be reduced, thus inducing late reactions in case of the occurrence of a critical event or that drivers may manifest over-reliance upon the system, which also induces a delayed avoidance response. The indicators used to study behavioural changes in these scenarios were reaction time, braking force, time to collision, minimum time headway ... and the number of collisions.

The main results were that drivers generally reacted later and/or with reduced safety margins when driving with ACC.

For example, Nilsson and Nabo (1996) found that reaction times were longer when using ICC systems. Hoedemaeker and Brookhuis (1998) observed that in an emergency stop scenario (where the lead car suddenly braked and came to a complete stop) the average maximum braking was larger and the average minimum TH was smaller when driving with ACC. In the same kind of scenario, Rudin-Brown and Parker (2004) found that drivers reacted more slowly and responded within a safe margin less often, when using ACC. During a simulated failure of the ACC system, they also found that drivers delayed their intervention until headway was very short. Törnros et al. (2002) studied several scenarios when driving on motorways and on rural roads. Scenarios included approaching other cars and traffic queues, and overtaking cars at various speeds. For most scenarios, the minimum time to collision was shorter with ACC than without.

The most critical scenario in terms of safety was the approach of a stationary queue, scenario that could not be dealt with by ACC. Nilsson (1995) observed that some ACC-drivers reacted too late and collided with the vehicle in front (four drivers out of ten). The author suggests that the collisions could neither be explained by increased driver workload nor by decreased level of alertness but were rather likely due to the driver's expectations that the ACC system would cope with the situation.

In a scenario simulating a failure of ACC (ACC accelerates when there is a vehicle in front of the driver's vehicle), Stanton et al. (1997) also observed that some drivers where late in reclaiming control of the vehicle and collided with the lead vehicle (four drivers out of twelve). The authors suggest a possible relationship between the level of workload and the driver's ability to reclaim control.

To sum up, driving with ACC generally induced delayed avoidance responses to changes in the driving situation, associated in some cases with harder braking actions. Delayed responses were either attributed to reduced attention to the driving task and/or to driver over-reliance upon the system.

It should be noted that these results were obtained in short term exposure to ACC driving. As indicated in Chapter II, studies on the learning process suggested that driver intervention in take-over situation improved as drivers gained experience with the system (Kopf and Nirschl, 1997; Kopf and Simon, 2001, Weineberg et al., 2001).

4.3.4 Drivers acceptance of ACC systems

In general, the results suggest that most drivers had a positive attitude towards ACC systems. However some differences may exist, depending on the characteristics of the drivers (Hoedemaeker and Brookhuis, 1998, Ward et al, 1995) and the characteristics of the ACC systems studied (Hoedemaeker and Kopf, 2002). Furthermore, some studies indicated that ACC systems under investigation was found rather easy to learn and to use (Nilsson, 1995; Fancher et al., 1998) and that most drivers trust in ACC (Nilsson, 1995), even though a failure of the ACC system occurs during the trial (Rudin-Brown and Parker, 2004).

4.4 Further research

The results of the literature review suggest several orientations for future research on behavioural adaptation. They are briefly suggested below:

- There is a need to clarify the models used for studying behavioural adaptation (which governs the choice of variables and indicators as well as the interpretation of the results) and for structuring the results with respect to design and safety assessment requirements.

- Many interacting variables may account for behavioural adaptations and their inter-correlations have to be more precisely established. This concerns for example, links between workload and driver ability to reclaim control as well links between mental models of the system, trust in the system and behavioural changes (see for example, Stanton, 1998, Rudin-Brown and Noy, 2003).
- More research is needed for understanding how drivers learn to share the control of their driving with new support systems, in order to perform the overall driving task efficiently and safely. This issue is particularly relevant if we assume that in the future several support systems will be integrated in the vehicle.
- It has also been stressed that the learning process is crucial for helping drivers to built appropriate representation of the assistance afforded by the support system and for « calibrating » their trust in it. Research in this area should provide useful information for designing « self-explaining » support systems and for offering the drivers additional supports likely to facilitate their learning process (Kopf and Simon, 2001; Manstetten et al. 2003).
- Finally, as it is the case for many driver support systems, real long-term effects need still to be examined.

5 Mobile phone

5.1 Introduction

Mobile phones were expensive and bulky when they first emerged. However, modern mobile phones are small, compact, easy to use and have become an essential part of life for many people. They enable people to maintain contact with family, friends and business associates. As well as the general communication benefits, access to a mobile phone also provides safety benefits by enabling people to alert breakdown or emergency services when necessary.

However, there is considerable concern that using a mobile phone while driving creates a significant accident risk to the user and to other people on the road, because it distracts the driver, impairs their control of the vehicle and reduces their awareness of what is happening on the road around them.

5.2 Effects on assisted drivers' performance and mental processes

The main effect of using a mobile phone on driver's activity is distraction. Using a mobile phone divides driver's attention and then affects driver's ability to drive safely. We can talk about *physical distraction*, *cognitive distraction* and *visual distraction*. Physical distraction comes from taking one's hands off the car controls in order to dial or compose a text message. This is reduced with hands-free phones, especially those with voice-activated dialling, but is not non-existent. Cognitive distraction is related to a mental distraction, for example, concentrating on a conversation. Visual distraction comes from looking at a telephone keypad in order to dial, or reading or composing a text message. Either physical activity or visual activity may cause cognitive distraction.

5.2.1 Physical Distraction

When using a hand-held mobile phone, drivers must remove one hand from the steering wheel to hold and operate the phone. They must also take their eyes off the road, at least momentarily, to pick up and put down the phone and to dial numbers. While using a hand-held phone, the driver must continue to simultaneously operate the vehicle (steer, change gear, use indicators, etc) with only one hand. Although the physical distraction is far greater with hand-held phones, there is still some physical activity with hands-free systems. Even though they do not need to be held during the call, the driver must still divert their eyes from the road to locate the phone and (usually) press at least one button.

Research has shown that manual dialling (i.e. using a hand-held mobile phone) impairs drivers' vehicle control (especially lane position and maintenance of appropriate speed) and reduces drivers' traffic awareness, resulting in slower reaction times and less use of mirrors. Manual dialling significantly interfered with the driver's ability to follow the road in an optimal manner, led to a significant increase in accident risk (Department of California Highway Patrol, 1987), caused considerable distraction, and this could impact on safety (Steven, and DAO, 1997).

Using hands-free mobile phones has less effect on drivers' vehicle control, but still does decrease their situational awareness and increase their braking reaction times (NHTSA, 1997). Hand-held mobile phones cause considerable distraction, but this effect may be reduced with hands-free phones, although there is still some cognitive distraction caused by the mental effort of telephone conversation with advanced aids. It has been found that even brief casual conversations under light traffic conditions have a small impact on a driver's mental workload and so are unlikely to have a discernible safety effect.

Therefore, as it has been recently suggested by the Independent Expert Group on Mobile Phones, formed by the British Government (Stewart, 2000) *the chance of an accident appears to be equally elevated for hands-free and hands-held use*, and this effect is almost certainly due to the distracting effect of the conversation. Similar conclusions have been reached by Nunes and Recarte (2002) who found that low demanding phone conversations produced null or low effects and high demanding phone conversations affected significantly the visual processing capacities. Talking on a hands-free phone is like talking with a passenger but the conversation content and its complexity are really potential distracters. Also, results found by Strayer et al (2001) showed that using a mobile phone while driving creates a serious distraction, which is caused by the driver's active engagement in the conversation rather than the physical interference of holding the phone. Similar results had been found by Strayer, Drews and Johnston (2002).

5.2.2 Cognitive Distraction

When mental (cognitive) tasks are performed concurrently, the performance of both tasks is often worse than if they were performed separately, because attention has to be divided, or switched, between the tasks and the tasks must compete for the same cognitive processes. When a driver is using a hand-held or hands-free mobile phone while driving, she or he must devote part of their attention to operating the phone and maintaining the telephone conversation and part to operating the vehicle and responding to the constantly changing road and traffic conditions. The demands of the phone conversation must compete with the demands of driving the vehicle safely. Using a mobile phone while driving had little effect on simple, automatic driving skills, but did impair drivers' traffic skills and responses to other vehicles (Brookhuis et al, 1991). Using a mobile phone delayed the drivers' adaptation to the changing speed of the vehicle in front and lengthened their reaction time to the appearance of brake lights of the lead vehicle (although the latter was not statistically significant). Dialling a telephone number in city traffic conditions significantly impaired steering wheel movements.

Sometimes drivers are not aware of the effect of using a mobile phone on performance and mental processing. Boase, Hannigan, and Porter (1988) interviewed nine people who regularly used a hands-free mobile phone for work-related calls while driving. The results revealed that they did not believe that using the phone affected their driving performance because they could adapt their speed or end the call if necessary. However, when they participated in simulated driving tasks of varying complexity on a computer (not a driving simulator) and had to respond to mobile phone calls, their performance was significantly worse during both simple and more complex phone conversations. So, although they did not believe using the phone affected their driving, in reality it did.

Mental workload

Research has shown that holding car-phone conversations while driving increases drivers' mental workload and stress levels and impairs their driving performance, particularly by slowing their response times (Parkers, 1993, Parkers et al, 1991, Lamble, 1999, Reed and Green, 1999; Direct

Line Insurance, 2002). Using the mobile phone increased the mental workload of the drivers on both the easy and difficult routes (Alm and Nilsson, 1994). Surprisingly, using the phone impaired driving performance more on the former than on the latter, perhaps because the subjects appointed the telephone task as the primary task when driving was easy. When the driving task became more demanding, the subjects may have regarded driving as the primary task and the telephone task as secondary. Furthermore, McCarley, Vais, Pringle, Kramer, Irwin, and Strayer, (2001) have found that the interference imposed by conversation affects driver's ability to detect events within complex traffic scenes.

Situational awareness

Beside mental workload, *situational awareness* is also affected by using a mobile phone. Situational Awareness (SA) is formally defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1988). Thus, there are three levels of situation awareness, each of them implying different mental processes.

- Level 1 situation awareness is where we look and perceive basic information.
- Level 2 situation awareness is where we think about and understand the meanings of that information.
- Level 3 situation awareness is where we use the meanings in order to anticipate what will happen ahead in time and space.

Parkes and Hooijmeijer, (2000) asked fifteen subjects to drive on a driving simulator for 15.5 miles on a single carriageway rural road with traffic in front of and behind them and on-coming vehicles. They were told to observe the speed limits and expect some severe weather conditions. They were asked a series of questions on a hands-free phone during the drive, and their reaction times, braking profiles, lateral position, speed, and situational awareness were measured. Reaction times were significantly slower during the early part of the phone conversations, but improved as the phone call proceeded. However, when using a mobile phone the drivers took an average of 200 metres longer to respond to a change in the speed limit. The simulation was stopped at various points and the drivers were asked questions about the traffic conditions. Using the mobile phone resulted in a significant deterioration of the drivers' awareness, to such an extent that they had very little awareness of what was happening on the road around them.

Behavioural adaptation

Therefore, it seems that using a mobile phone has an effect on drivers´ performance, mental workload and situational awareness. In particular, mental workload increased when using a mobile phone. However, this effect decreased as they became more accustomed to using the phone while driving (Brookhuis et al, 1991). Surprisingly, the variations in lateral position (swerving) were less while using the telephone than when not, especially while driving on the motorway. This may indicate that drivers increased their alertness to compensate for using the phone, which is a typical indication of *behavioural adaptation*.

Indications of *behavioural adaptation* were observed in a study by Fairclough et al (1991) which involved 24 drivers driving on real roads while holding a conversation (a role-play negotiation) on a hands-free mobile phone, holding a conversation with a car passenger, and a control condition of just driving. The results showed that holding a conversation at the same time as driving increased the drivers' mental workload and their stress and frustration levels. The drivers also took longer to complete their driving routes while holding the conversations, possibly because they reduced speed to be able to devote more of their concentration to the conversations. The stress caused by negotiating on the mobile phone was significantly higher than that caused by negotiating with the passenger. Similar results were found by Haigney (1998). In his study, the drivers' performance was assessed before, during and after the call, and their heart rate was monitored throughout the exercise. Drivers' maintenance of speed was significantly impaired when using either a hand-held or hands-free mobile phone when driving both manual and automatic cars. This reduced responsiveness continued for at least 2.5 minutes after the call. Drivers' also significantly reduced their following distance from the vehicle in front when using either handheld or hands-free phones and they continued to 'tailgate' after the call. Participants' heart rates rose significantly during the calls, indicating increased stress.

More indications of *behavioural adaptation* were found in a study by Ishida et al, (2001) in which the drivers were more likely to deviate from their lane position when using a mobile phone, especially a hand-held one. Those drivers who had to pick up the phone from the passenger seat to answer it took their eyes off the road for almost 2 seconds. However, there was also a tendency for the driver to stare straight ahead while using the phone and to look around less.

However there is also some *evidence against behavioural adaptation*. Alm and Nilsson (1995) found that using the mobile phone slowed the drivers' reaction time, especially older drivers'. Moreover, the drivers did not compensate for their slower reaction times by increasing their following distances, perhaps because they were unaware that using the phone was slowing their reactions. The authors calculated that the drivers in the study would not have been able to avoid a collision if the vehicle in front had braked sharply.

Behavioural adaptation could be the explanation for the null effects sometimes observed on driver's performance (Parkes et al, 1991). Noy and Cassidy (1999) had found that drivers experienced greater mental workload when using a mobile phone and when talking to a passenger than when driving alone, but appeared to adapt to the increased cognitive demands of the conversations.

Behavioural adaptation was evident in a study by Haigney, Taylor, and Westerman (2000) in which they found support for the hypothesis that drivers engage in compensatory behaviour and attempt to reduce workload when using a mobile phone to enable perceived required safety margins to be achieved.

5.2.3 Modulation variables

The effects of using a mobile phone are modulated by a series of variables that should be taken into account in order to predict driver's performance and cognitive processing.

Type of conversation

The type of conversation modulates the effect of using mobile phones. This has been observed in a driving simulator study by Briem, Hedman and Radeborg (1998) who investigated the use of a hands-free mobile telephone while driving on firm and slippery roads. Half the driving was on firm and half on slippery road. Twenty participants (mean age was 33 years old) performed three 20 min. secondary task blocks, with (i) simple and (ii) difficult telephone conversation (specifically involving judgement and memory), and (iii) car radio use. Driving behaviour was classified in 4 categories, with driving on (i) a clear road, and with (ii) obstacles, (iii) communication, and (iv) instrument manipulation. The results showed that driving performance was clearly deteriorated on a slippery road, especially during instrument manipulation (radio and telephone). Easy telephone conversation was associated with least performance decrement, while difficult conversation tended to affect driving adversely. Prolonged manipulation of the telephone produced a performance decrement, particularly under conditions that put heavy demands on the driver's attention and skill. Cognitive performance was also deteriorated for the difficult telephone conversation, as regards judging the content of simple sentences and recalling the first words of sentences. There is a complex trade-off between performance on concurrent tasks, driving and mobile telephone communication. This is shown in interference between similar sub-tasks, both primary and secondary (steering, speed control, instrument manipulation), and in a mutual interference between the primary and secondary tasks (driving - cognitive performance). This resulted in progressive decrements in both the simulated driving and the quality of an on-going telephone conversation, both as the driving became more difficult (and attention demanding) and as the topic of the conversation became more difficult (and attention demanding). Nunes and Recarte (2002) had found that low demanding phone conversations produced null or low effects and high demanding phone conversations affected significantly the visual processing capacities. Talking on a hands-free phone is like talking with a passenger but the conversation content and its complexity are really potential distractors. Active engagement in the cell phone conversation is necessary to produce interference. Strayer, Drews and Johnston (2002) had found results that rule out interpretations that attribute the deficits associated with a cell phone conversation to simply attending to verbal material, because dual-task deficits were not observed in a book-on-tape listening control task.

Complexity of the driving task

The *complexity of the driving task* is also a factor that interacts with the effect of using a mobile phone. A Canadian research (Insurance Corporation of British Columbia, 2000) on an off-road test track assessed drivers who listened and responded to taped messages while driving. They periodically encountered traffic lights, pop-up targets around which they had to swerve and had to turn left into a traffic stream. When responding to the taped messages, the drivers were more likely to stop (rather than ‘run’ the lights) when the traffic lights changed, possibly to allow themselves to divert their attention to the phone task. When the drivers had to react to the unexpected pop-up targets, their reactions were slower and they swerved around them at greater speeds, when the message was being played than when not responding to the taped message. When turning left, drivers took significantly riskier decisions when listening and responding to the messages. The study concluded that listening and responding to relatively complex messages (such as when using a hands-free mobile phone) were found to ‘significantly degrade driving performance’. The impairment was related to the complexity of the driving task, such that using the phone would cause more problems in more complex driving situations.

Individual differences

The individual differences must be taken into account because a recent study by Sullman, and Baas (2004) has shown a significant correlation between the frequency of cell phone use and crash involvement, once the contributions of the demographic and descriptive variables had been partialled out the relationship between the two was no longer significant. This result is in contrast to previous research which has found using a mobile phone whilst driving significantly increases the risk of being crash involved (Redelmeier and Tibshirani, 1997; Violanti, 1998; Violanti and Marshall, 1996).

Pachiaudi and Chapon (1994) observed seventeen drivers driving a simple route on a driving simulator, while holding a phone conversation. Two of the seventeen subjects were able to use the phone and maintain a constant speed. A further nine had problems doing the two things simultaneously, but coped by reducing their speed to give themselves more time. The remaining drivers faced ‘mental overload’ and failed to maintain a constant speed. They seemed unable to do the two tasks (driving and using the phone) simultaneously and so tended to switch between them, sometimes giving greater importance to the phone conversation and sometimes to driving. In some cases this resulted in a speed decrease, in others a speed increase.

Using a mobile phone while driving may cause more problems for older drivers than younger ones (Hayes et al, 1989). There is evidence that older drivers require more glances to instrument panels to retrieve necessary information, require more time to complete instrument tasks and require more time to move their eyes between the road and an instrument display. Similar results were found by Woo and Lin (2001). In their study, results showed that using a mobile phone while driving significantly increased the time it took drivers to respond to the various traffic situations. The response times of older drivers were affected to a greater extent than those of younger drivers.

Using mobile phones might affect differently to novice and expert drivers. Inexperienced drivers have difficulties in allocating their visual attention between driving and a secondary task (changing a radio cassette, dialling a mobile phone number or tuning a radio), as they make more short ineffective glances and more long risky glances (Wilkman et al, 1998). The long glances away from the road made by novice drivers result in large deviations in lane position. Piechulla, Mayser, Gehrke and König (2003) studied the workload associated to driving while using a hands-free mobile telephone connected to an adaptive man-machine interface that filters information presentation according to situational requirements. The results showed that, whereas the mental workload for experienced drivers is reduced significantly in the adaptive telephone condition, this is not the case for beginners.

Different dialling mechanisms

Salvucci (2001) has compared the effects of *different dialling mechanisms*. In his study, drivers used four different dialling interfaces: (1) Full-manual; (2) speed manual; (3) Full-voice; and (4) speed-voiced. After some practice, eleven drivers (five women and six men aged from 19 to 32) drove the one-lane road at a speed of approximately 60 mph (96 km/h) and were asked to dial the phone at 20s intervals. Concerning the effects on driver performance, it was found that the full-manual interface had large significant effects, whereas the speed-manual interface had small significant effects, and the voice interfaces had no significant effects. About dialling time, the speed-manual interfaces required the least time, followed by speed-voiced interface, the full-manual interface, and finally the full-voice interface.

5.2.4. Motivational and emotional effects

The risks associated with mobile phone use when driving are not simply limited to physical and mental distraction. They also involve more aggressive driving, manifesting itself in tailgating other drivers to intimidate them to move over, dangerous overtaking and lane changing (Petica, 1995).

5.3 Summary

Many studies, using a variety of different research techniques, have reached similar conclusions: using a mobile phone while driving adversely affects driver performance in a number of different ways. It impairs:

- Maintenance of lane position
- Maintenance of appropriate and predictable speed
- Maintenance of appropriate following distances from vehicles in front
- Reaction times
- Judgement and acceptance of safe gaps in traffic
- General awareness of other traffic.

It also increases:

- Mental workload
- Risk of having an accident

These impairments of driving performance are worsened in the case of inexperienced and older drivers.

Much of the research has assessed using hands-free phones and demonstrates that these still distract drivers and impair safe driving ability, even when driving automatic cars. There is also evidence that using a mobile phone while driving causes greater problems for those drivers who already have a higher accident risk, namely young, novice drivers and elderly drivers.

Specifically, we can conclude with the following relevant ideas obtained from the revised literature.

Lateral Position

‘Lateral position’ is the vehicle’s position in relation to the centre of the lane in which they are driving. The majority of research indicates that lateral position is adversely affected by mobile phone use, meaning that a driver’s lateral position varies significantly when manually placing a call using a phone keypad on a hands-held or hands-free system - even when driving on a straight road with no other traffic.

Maintenance of Speed

The majority of research indicates that drivers find it more difficult to maintain an appropriate and predictable speed while using a mobile phone which sometimes leads to reducing their speed and sometimes to increasing it.

Following Distances

When using a mobile phone, drivers are more likely to reduce their following distance from the vehicle in front. When this effect is coupled with slower reaction times, the risk of a collision is even greater.

Reaction Times

The evidence indicates that drivers take longer to detect and respond to changes, such as a vehicle in front decelerating, which leads to slower braking times. Braking response and overall reactions are slower in drivers using a mobile phone, regardless of their age. A driver's ability to react to changes in the speed of the vehicle in front is reduced by 0.6 seconds (Brookhuis et al (1991:315).

Gap Acceptance

Using a mobile phone also impairs drivers' judgement of acceptable gaps in traffic streams, leading to drivers entering or accepting gaps that are not large enough. They tend to try to drive through gaps smaller than their car when using a phone compared to driving without using a phone.

Situational Awareness

Using a mobile phone reduces drivers' awareness of what is happening around them on the road. Some evidence indicates that when using a phone, drivers have little awareness of whether or not there is other traffic around them and what it is doing. Drivers using a mobile phone are less likely to check their mirrors in a busy 'ring-road' urban condition than any other road situation. Arguably this is the condition in which drivers should be using their mirrors most often in order to negotiate traffic safely.

Mental Workload

Most of the studies show that using a mobile phone while driving increases drivers' mental workload, often resulting in higher stress and frustration levels. There is evidence that drivers have to switch their attention between driving and using the phone, sometimes giving more attention to the phone call than to the road situation.

Accident Risk

Although few studies have been conducted to assess the increase in accident risk caused by using a mobile phone when driving, those performed confirm that the impairment created by using a mobile phone does result in an increased likelihood of being involved in an accident. However, the lack of a system to record whether or not drivers who are involved in an accident have a mobile phone in the vehicle and if it was being used, means that it is difficult to calculate the increased risk and to estimate the level of accidents caused, or contributed to, by drivers who are using mobile phones.

Age and Driving Experience

There is evidence that undertaking secondary tasks while driving, such as using a mobile phone, causes greater problems for inexperienced drivers (who already have a higher accident risk) than experienced ones. There is also evidence that older drivers find it more difficult to conduct two tasks concurrently, and their response times are particularly impaired.

Hand-held and Hands-free Phones

The evidence clearly shows that manually dialling telephone numbers, especially long numbers, is a significant mental and physical distraction. Hands-free phones reduce the physical distraction, and speed dial facilities or voice-activated systems reduce time required to dial numbers. However, even these systems still cause substantial cognitive distraction, resulting in significant driver impairment.

5.4 Future developments

Mobile phones may develop to such an extent that integrated in-car systems would monitor driver behaviour and the traffic situation and when necessary, alert the driver and the person to whom she or he is speaking, and even terminate the call if necessary (Parkers, 1993). However, Piechulla, Mayser, Gehrke, and König, (2003) have found results that showed a reduction of mental workload in the adaptive telephone condition, where incoming telephone calls are not signalled to the driver, but redirected to the mailbox whenever the workload estimation exceeds threshold. Video ratings show that while the workload for experienced drivers is reduced significantly, this is not the case for beginners.

Other Distractions

The evidence indicates that talking to a passenger does not cause the same level of distraction as using a mobile phone, perhaps because of the visual communication clues that accompany a face-to-face conversation and because a passenger can see the traffic situation and adapt the conversation accordingly. The use of a mobile phone has been compared with tuning a radio or changing a tape cassette, and the results usually show that the mobile phone causes more problems. However, tuning the radio has also been found to distract drivers and impair their performance.

An area of increasing concern is the growth in the number and complexity of electronic devices being fitted in cars: navigation devices, Internet computers, fax machines, even small televisions. While some devices, such as navigation equipment, may aid safe driving, most of these items should not be used while driving. But, just as drivers use mobile phones while driving, many are likely to use other devices as they drive. The distraction and accident risks seem likely to be similar to those created by mobile phones.

6 Behavioural Effects of Use of Automation on Pilots

6.1 Crew/Automation Interaction in Space Transportation Systems: Lessons Learned from the Glass Cockpit

The choice to take into consideration the Aviation domain is due to the large amount of material and experience JRC has concerning cockpit automation. Furthermore the identification of the effects of cockpit automation on pilots' performance can provide useful hints to the development of in-vehicle automation as there is a parallelism between "driving" environment and "flying" environment.

The progressive integration of automation technologies in commercial transport aircraft flight decks -- the "glass cockpit" -- has had a major, and generally positive, impact on flight crew operations such as economic efficiency, increased precision and safety, and enhanced functionality within the crew interface (Rudisill, 2000).

These enhancements, however, may have been accrued at a price, such as complexity added to crew/automation interaction that has been implicated in a number of aircraft incidents and accidents. This statement is the outcome of several research actions that have been carried out since the 80' (Bainbridge, L. 1987) and is still the object of a number of controversies (Masson, M., and Y. Koning, 2001; Maurino, D. E., J. Reason, N. Johnston, and, R. B. Lee, 1995; Sarter, N. B., and D. D. Woods, 1994). A more detailed discussion on this issue would require a too long analysis and review that is outside the scope of this document. As an example the issue 2 vs. 3 pilots has been studied and justified by many activities such as the work of H.W. Orlady (1999) that contains the essence of this subject.

Some of these benefits are:

- Economic Efficiencies: Automation has provided savings in a number of domains, by enhancing efficiencies (e.g., in fuel use) and by reducing operating costs (e.g., by enhanced reliability, reduced maintenance requirements, and reduced crew size);
- Enhanced precision: Automation allows more precise guidance and navigation, enhanced vehicle position control, and better energy management;
- Enhanced safety: Automation enhances safety by providing for the rapid detection and actuation of emergency systems beyond the performance capabilities of the crew.
- *Economy of cockpit space and enhanced information display*: The glass cockpit has allowed increased information integration while also affording new information display methods and simplifying crew operations (e.g., number of procedures and procedure steps).
- *Reduced crew workload*: Automation reduced workload such that the flight crew could be reduced from three to two. Automation also removed crew responsibility for many tedious, time-consuming, and potentially interfering) tasks (e.g., auto-tuning radios).

6.1.1 Crew/Automation Interaction Accidents & Incidents in the Aviation Domain

Following is a brief description of a sample of incidents and accidents involving flight crew interaction with the automation on their aircraft. These examples are indicative of the types of problems that have been associated with the progressive introduction and use of automation on commercial transport flight decks.

"Strong and silent" automation, feedback, and information display.

Automation has been called "strong and silent" having significant capability to control the vehicle, but often provides little feedback to the crew concerning its present state and its operation. For example, in 1985, a China Airlines flight crew lost power in one engine during automated flight of a Boeing B747. The automation compensated for failing engine performance until its control limits were reached, at which point the automation failed and the aircraft went into an uncontrolled dive. The pilot was ultimately able to disengage the automation and recover the aircraft. The automation essentially masked the approaching onset of its control limits and the impending loss of control of the vehicle.

Pilots as "system monitors" and crew over-confidence in automation capabilities

The pilot's role has changed with automation, from "direct controller" to "system monitor." At times, pilots have become complacent and have over-depended on their automation.

In 1996, an American Airlines B757 crashed in Cali, Colombia, killing all onboard. There were a number of underlying causes for this accident, many of which related to the automation and the flight crew's training. The root causes of this accident included:

- inadequacy of the navigational database used by the automated FMC;
- The flight crew's *failure to maintain navigation situation awareness;*
- The flight crew's *misprogramming of a navigational waypoint;*
- Crew task overload caused by unexpected runway changes (and the task load associated with re-programming the FMC);
- Crew training that emphasized automation use at the expense of maintaining crew manual control and navigation skills; and
- Language difficulties.

6.1.2 Crew/Automation Interaction Issues & Problems

General categories of crew/automation interaction problems and issues are identified and briefly described below.

- Safety and Crew Error
- *The Pilot as System Monitor*
- *Automation Complexity and Modes*
- *Distancing*
- Command and Authority

- Crew Interaction & Cockpit Resource Management
- *Crew Workload*
- *Display and Control Design*
- *Fatigue, Stress, Complacency, & Boredom*
- *Loss of Manual Skills*
- Crew Training and the Automation “Mental Model”
- Level of Capability

6.2 Automation and Situation Awareness

Originally a term used in the aircraft pilot, situation awareness has developed as a major concern in many other domains where people operate complex dynamic systems.

Situational Awareness (SA) is formally defined as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” (Endsley, 1988a)

For instance in aircraft environment operators must be aware of critical flight parameters, the state of their on-board systems their own location and the location of important reference points and terrain and the location of other aircraft along with relevant flight parameters and characteristic. A great deal has to do with how the operators interpret the information they take in.

Automation can be seen to directly impact SA through three major mechanisms:

- *Changes in vigilance and complacency associated with monitoring;*
- *Assumption of a passive role instead of an active role in controlling the system;*
- *Changes in the quality or form of feedback provided to the human operator.*

Complacency, over-reliance on automation is one of major factor associated with a lack of vigilance in monitoring automation. Complacency has been attributed to the tendency of human operators to place too much trust in automated systems. Monitoring problems have been found with systems that have a high incidence of false alarms, leading to a lack of trust in the automation. Numerous failures have been reported by aircrews to heed automatic alarms, leading to serious accidents. Even though the system provides a noticeable visual or auditory signal, the alarms are ignored or disabled by flight crew who have no faith in the system due to its high false alarm rate. Thus *significant reductions in situation awareness can be found with automated systems as people may:*

- *Neglect to monitor the automation and its parameters;*
- *Attempt to monitor them but fail due to vigilance problems;*
- *Be aware of problems via system alerts but not comprehend their significance due to high false alarm rate.*

The fact that operators are passive observers of automation instead of active processors of information may add to their vigilance problems in detecting the need for manual intervention and in re-orienting themselves to the state of the system in order to do so. *Turning a human operator form a performer into an observer can negatively effect SA even if the operator is able to function as an effective monitor* and this can lead to significant problems in taking over during automation failure.

Without appropriate feedback people are indeed out of the loop. They may not know if their requests have been received, if the actions are being performed properly or if the problems are occurring.” (Norman, 1989).

In some cases the design of automated intentionally conceals information form the operator. Some auto feathering systems have neglected to notify pilots of their actions in shutting down engines leading to accidents (Billings, 1991). In some noticeable accidents the fact that the automated systems had failed was not clearly indicated to the operator as in the Northwest Airlines accident in Detroit (National Transportation Safety Board, 1988). *The design of many systems posses a considerable challenge to SA through the elimination of or change in the type of feedback provided to operators regarding the system's status.*

One of the major impediments to the successful implementation of automation is the difficulty many operators have in understanding automated systems even when they are attending to them and *the automation is working as designed*. This may be partially attributed to the inherent complexity associated with many of these systems, to poor interface design and to inadequate training.

The development and the maintenance of SA involves keeping up with a large quantity of rapidly changing system parameters and then integrating them with other parameters, active goals and one's mental model of the system to understand what is happening and project what the system is going to do.

Many problems have been documented with a lack of understanding of automated systems in aircraft by the pilots who fly with them. McClumpha and James (1994) conducted an extensive study of nearly 1000 pilots finding that the primary factor explaining variance in pilots' attitude toward automation in aircraft was their self-reported understanding of the system. With increased complexity providing information clearly to operators so hat they understand the system state and state transitions become much more challenging. If operators are unable to properly interpret observed system actions and predict future system behaviour they will have significant SA problems.

Automation does not always results in problems for SA. Weiner (1985) points out that automation has worked quite well and has accompanied a dramatic reduction in many types of human errors. He believes *that automation can enhance SA by reducing excessive workload, the display clutter and the complexity associated with manual task performance and through improved integrated displays.*

*Curry and Ephrath (1997) found that monitors of automatic system actually performed **better** than manual controllers in a flight task.* As monitors subjects may have been able to distribute their excess attention to other displays and tasks.

6.3 Human Interaction with aircraft cockpit displays

Flight modes take over the actual pilot work and flight responsibility, but the highest authority remains with the pilot (Schmelzer, 1997). He can interact and interrupt an autopilot mode whenever it is necessary to take control. Consider that this requires information about the flight mode he is currently engaged in. The technological evolution led to the establishment of the glass-cockpit and within this evolution the role of design and ergonomics becomes increasingly important. To attain improvement the cockpit has to be centred and designed around the pilot, which refers to the user-centred design. (Wickens, 1997)

To back this up the following numbers taken out of a survey of the German Pilot Association emphasize the need for glass-cockpit modification. The survey reveals that 67 percent of the pilots asked felt occasionally overloaded with visual information. While 31 percent of the pilots who fly conventional cockpits said that they would like a higher degree of sensation, this number increases to 42 percent among the pilots flying an older generation of glass-cockpits. Whereas 65 percent of the pilots flying the most modern aircraft cockpit used in Airbus A320/321,A330/340 asked for improvements in this area. Interestingly, 71 percent of the *pilots would appreciate an increase in usage of acoustical information as an additional sensory source of information.* Also worth mentioning is that the basic set-up of the cockpit design does not show remarkable differences unlike the assumption that an improvement in display technology also implies an improvement in cockpit design. The pilots demand for acoustical information enhancement, reduction of graphical information overload plus support with the necessary background information of new cockpit interfaces.

Head up displays (HUD's) were developed and are used for military purposes. The major advantage is that the pilot doesn't need to look down to obtain information. He can keep his eyes straightforward. The 'head-up-display' projects the most important data in front of the windshield. The projection is focused at infinity so the pilot does not have to accommodate his eyes to read this information in detail. The direct environmental contact is maintained. Therefore, the HUD-display offers possibilities to enhance flight safety. However, there is also a downside. The *information presented can mask events and objects outside of the pilots cockpits by overlapping imagery* (Wickens, 1997). Also the information presented can become cluttered. That can result in attention problems and decrease in performance. A suggestion is to use different light intensities and colours. Another big advantage is the possibility to conform shapes, like the shape of a runway. Also, the principles of pictorial realism moving parts and ecological interfaces can be exploited to fully utilize the potential embedded in HUD-displays. Examples for this are the moving arrow in vertical direction to show the velocity and the moving arrow in horizontal direction used to determine the heading of the aircraft.

Auditory and visual perception occupy different regions of the cognitive brainwork. *Many accidents happen while the pilot is under heavy visual workload.* Differently from visual systems the auditory ones do not require direct attention to a certain direction to perceive stimuli. There is no need to scan a display or to search for a certain value. Auditory stimuli have the advantage of attracting attention immediately. *The danger of trusting in auditory signals lies in false interpretation or wrong understanding of what was emitted.* Also, one has to consider that most communication within the cockpit is auditory. Thus, two auditory information sources at the same time could lead to confusion and distracting.

6.4 Cockpit Automation

Comments from a number of periodicals, papers, journals and other documents show that: cockpit automation increases, decrease and redistributes workload. It enhances situational awareness, takes pilots out of the loop, increases head-down time, frees the pilots to scan more often, reduces training requirements, increases training requirements, makes a pilot's job easier, increases fatigue, changes the role of the pilot, changes the nature of human errors increase flight safety and has an adverse effect on safety (Amalberti et al., 2000).

6.4.1 Positive effects of automation

In aviation automation is recognized as having contributed to major advances in the following areas:

- *Technical reliability;*
- *Fuel saving and reduce of operation's cost;*
- *Flying easier and safer thanks to fly-by-wire technology;*
- *Improved passengers' comfort;*

6.4.2 Drawback of automation:

On FMS (Flight Management System) generation aircraft a list of reaction to the automation has been done by Chidester:

- Crew operating more automated aircraft describe a transfer of some aircraft control to PNF (Pilot Non Flying);
- There are comfort differences in the use of automation among pilots. The more comfortable a member of the crew is with automation the more likely he/she will take the lead leaving the other members out of the loop;
- Automation transfers workload among phases of flight. The workload is particularly high on the ground, low in cruise and increases in approach cases where ATC requests differ from the planned flight;
- Automation changes *the timing of errors;*
- *Pilots show a tendency to use the extremes of the automation range;*
- *Pilots have difficulties in detecting or understanding automation failures;*
- *There is a tendency to try to correct an automation induced failure by manipulating automation rather than reverting to a lower automation level;*
- *Pilots lose some basic skills when they get used to fly automated aircraft;*
- *There are instances of complacency and lost of situational awareness when flying in automated way.*

Complacency is defined as a feeling of being at ease satisfied or comfortable. In the aviation Human Factor domain the term is used to characterize pilot's over reliance on automation.

A way to interpret complacency is in terms of boredom, hypo-vigilance, lack of attention or even lack of motivation to follow the standard procedures and professional practices.

Complacency is seen as automation induced since:

- Pilots' attention scanning pattern has been modified tending to make attention scanning more localized
- Pilots are more involved in checking that automation behaves as intended than flying the aircraft
- Since automation is particularly efficient and reliable pilots have learnt to rely on it. In this way they assume that everything works well as usual and they wait for confirming cues without structured expectations.

This kind of task is extremely boring and so there is an increased possibility to miss a mode change, to misunderstand the real behaviour of the aircraft or to not detect an abnormal auto-flight performance.

Billings (1997) has elaborated a set of fundamental automation design principles for Human centred automation in the aviation domain.

Premises:

- The pilot bears the responsibility for the safety of the flight
- Controllers bear the responsibility for traffic separation and safe traffic flow

Axioms:

- Pilots must remain in command of their flights
- Controllers must remain in command of air traffic

Corollaries:

- The pilot and the controller must be actively involved
- Both operators must be adequately informed
- The operators must be able to monitor the automating assisting them
- The automated systems must therefore be predictable
- The automated systems must also monitor the human operators
- Every intelligent system element must know the intent of other intelligent system elements

6.5 Summary

The nature and extend of behavioural changes associated with the use of individual driver support system

- Flight crew’s failure to maintain navigation situation awareness;
- Flight crew’s misprogramming of a navigational waypoint
- Crew Workload
- Fatigue, Stress, Complacency, & Boredom
- Loss of Manual Skills
- The Pilot as System Monitor
- Distancing
- Neglect to monitor the automation and its parameters;
- Attempt to monitor them but fail due to vigilance problems;
- Be aware of problems via system alerts but not comprehend their significance due to high false alarm rate
- Pilots show a tendency to use the extremes of the automation range;
- Pilots have difficulties in detecting or understanding automation failures
- There is a tendency to try to correct an automation induced failure by manipulating automation rather than reverting to a lower automation level;
- Pilots lose some basic skills when they get used to fly automated aircraft.

The conditions in which these changes take place

- Fatigue, Stress, Complacency, & Boredom
- Loss of Manual Skills
- Distancing
- Crew Workload

The reasons why these changes occur

- Automation Complexity and Modes
- Display and Control Design
- Turning a human operator form a performer into an observer can negatively effect SA even if the operator is able to function as an effective monitor
- Automation changes the timing of errors
- The design of many systems posses a considerable challenge to SA through the elimination of or change in the type of feedback provided to operators regarding the system’s status

7 Metrics and target values to study and assess driving behaviour

7.1 Context

This document summarizes the content of the deliverable D2.1, part I of the ROADSENSE project: a state of the art aiming to identify metrics used to study and assess driving behaviour. It is not exhaustive and some choices have been operated considering the goals of ROADSENSE project that may differ from the AIDE ones

The ROADSENSE project (Road Awareness for Driving via a Strategy that Evaluates Numerous SystEms) had as principal objective to develop a common industrial standard methodology for Human Vehicle Interaction (HVI) and Driver System Interfaces (DSI) assessment. Some recommendations were designed for testing HVI by measuring the behavioural effects induced by embedded new technological solution or combination of solution.

The consortium was composed of the following partners: Jaguar Cars, Renault SA, CRF, TNO, Porsche, University of Compiègne (Heudyasic), University of Clermont-Ferrand (LASMEA), University of Cranfield.

7.2 Behavioural metrics: major issues

The objective was to specify metrics and target values used for HVI and DSI assessment, based on safety and driving-support criteria.

7.2.1 State of the art

A state of the art was achieved from ISO documents, NHTSA studies reports, conference proceedings, books, specialised press, Internet forum, partners and internal reports.

At the end, 105 references, from 1973 to 2001, allowed to identify indicators helping evaluating workload induced by embedded system (ADAS or IVIS): subjective indicators, driving task performance indicators, secondary task indicator, comfort indicators, physiological indicators.

7.2.2 Indicators definition

It has been decided not to work on both comfort and physiological indicators, as definitions are missing for associated metrics and measuring techniques with objective metrics are often intrusive and heavy to use, so that an industrial standard is still far away.

Considering subjective measures, no automotive method has been identified. Most parts of method are scaled-based and were designed for aeronautics or nuclear industry. Some of them are frequently used for automotive studies: SWAT (Subjective Workload Assessment technique), NASA-TLX (NASA Task Load Index), and the simple OW (Overall Workload)

Among objective indicators of performance, two types are distinguished: driving task performance and secondary task performance indicators.

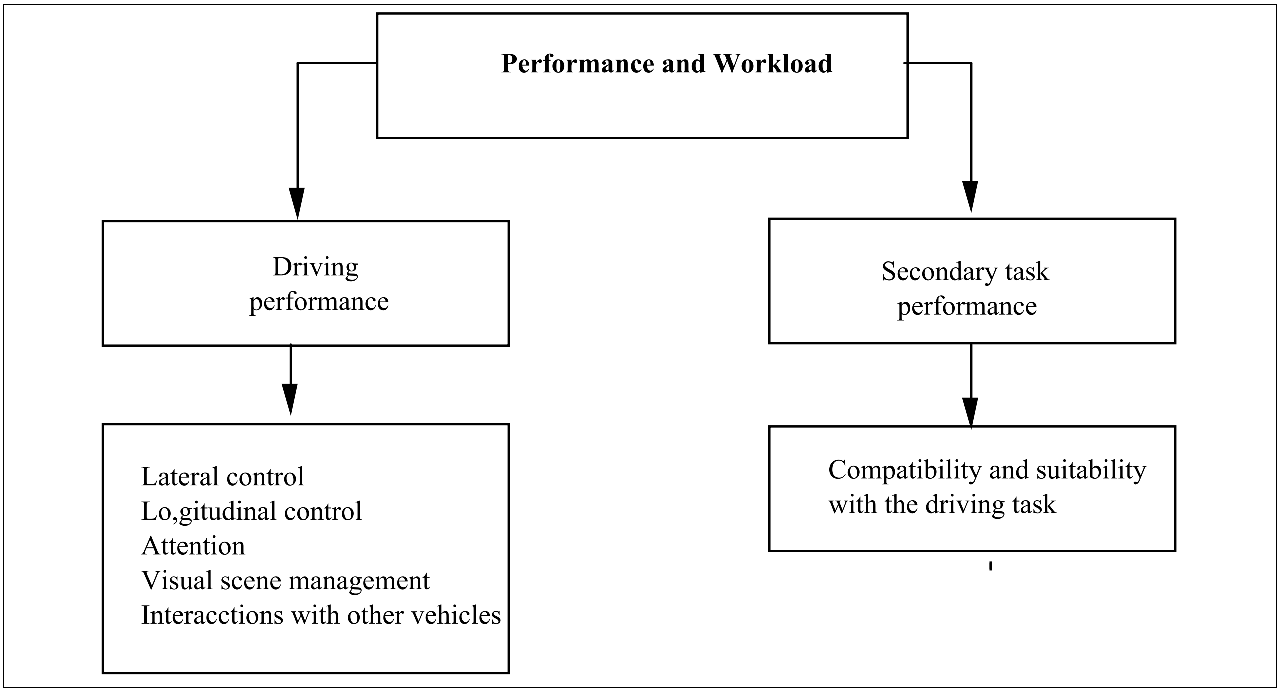

Figure 2. Schemes for objective indicators of performance

7.2.3 Metrics specification

In order to specify these indicators, 77 metrics have been identified as used for HVI assessment. From them, 46 were selected depending on there validity, sensitivity, feasibility and when needed expert opinion. (See Table 1)

Associated target values were not found for all selected metrics, and among those, which were reported, a variation area was difficult to specify considering the wide range of values and the conditions of variations.

Performance and driving workload indicators	Number of identified metrics	Number of selected metrics	Number of metrics with target values
Lateral control	14	8	4
Longitudinal control	3	2	0
Visual scene management	7	5	5
Interactions with other road users	13	5	2
Situation awareness	16	8	5
Compatibility and suitability	24	18	6
Total	77	46	22

Table 2. Metrics selection

Lateral control
Number of major lane deviation
Variance of steering wheel angle
Standard deviation of steering wheel angle
Standard deviation of lateral position
Steering entropy
Steering reversal rate (SRR)
Vehicle angular speed
Time to line crossing (TLC)
Longitudinal control
Mean speed
Speed Variance
Visual scene management
Glance duration on in-vehicle road information
Glance duration on driving information
Glance duration to any other areas
Visual demand (glance duration distribution among areas)
Decrease of rear-mirror glances frequency
Interactions with other vehicles
Time headway
Relative distance
Following distance
Duration of short inter-distance (<2sec)
Number of lane changing

Situation awareness
Reaction time
Braking reaction time
Reaction time and number of missing in PDT (peripheral detection task)
Speed of accelerator position variation
Number of emergency braking
Speed variation
Actions on pedal
Compatibility and suitability with driving
Number of actions on the system
Number of responses from the system
Dwell time (fixations + saccades) in an area
Number of fixations in an area
Lane occupation time
Glance duration
Glance frequency
Fixation duration
Task duration
Number of failures
Auditive Reading Time
Action time
System response time
Number of braking actions
Number of errors on braking
Number of actions on accelerator
Frequency of accelerator-foot-covering action

Table 2 Detailed list of selected metrics

As metrics take sense only if context is known, condition of tests are given each time they are known and factors that may influence results obtained with these metrics, are listed: road type and geometry, climatic conditions, drivers characteristics, etc. (Table 2). All factors have to be specified when designing test-scenario.

The dynamic of values taken by the metrics is given: for example, if decreasing and in which condition, with the influence of which factor.

7.3 Conclusion

This state of the art is very incomplete. It has to be updated, with newest references and upgraded with additional even “old” references and with additional metrics that were not selected.

What seems to be missing here:

- No driving task model was explicitly described
- No driving activity model was explicitly described
- As the goal was to keep independent from technology and from specific support system, some metrics may not appear even if they were identified during state of the art.

Nevertheless, even if a driving task model can lead to design other categories of metrics and add other metrics, those, which were identified, are still usable, but may be specified in more details (with target values?).

8 A proposed evaluation scheme for studying the long-term effects in driving behaviour

8.1 Introduction

The aim of this report is to present an evaluation scheme for studying the long-term effects in driving behaviour as a result of behavioural adaptation to an Advanced Drivers' Assistance System (ADAS), taking into consideration both the motivational, perceptual and cognitive factors that may lead drivers to adapt their behaviour but in different direction. Furthermore, the methodological aspects concerning longitudinal studies are also discussed in order to define the time considered as sufficient for a longitudinal study. The objective in AIDE SP1 is to evaluate the long-term effects of the variables in question in terms of performance changes or even behavioural changes.

8.2 Some facts regarding drivers' perceptual state

The main finding regarding drivers' reliance on Advanced Drivers' Assistance System (ADAS), especially for TTC information, is that humans have certain perceptual limitations in making accurate estimations of TTC (Taeib-Mainon and Shinar, 2001; Fairclough et al., 1997). Furthermore, it has been shown that drivers trust TTC information even though this information is purposefully inaccurate (Ben-Yaakov et al., 2002; Shinar and Schechtman, 2002). This finding has been interpreted as an indication of *drivers' awareness of their perceptual limitations on making accurate distance estimations and this is why they trust TTC warnings.*

In contrast, maintaining lateral position with peripheral vision is a learning ability that is considerably improved with driving experience –more than 50.000km– (Summala et al., 1996). But, there is no analogous improvement in maintaining a safety margin from the vehicle in front with peripheral vision, even with increased driving experience –more than 100000km– (Summala et al., 1998). *So reliance on TTC or TLC warnings seems to be affected in a different way because of the different learning effects in the use of visual information received from peripheral vision, as a function of driving experience.*

However it is debatable whether peripheral vision is the only information source for steering control both at straight sections and at curves. Recent findings on steering control at curves (Land and Tatler, 2001; Zitkovitz and Harris, 1999) suggest that proprioceptive information, namely vestibular and cervical signals, are the major inputs for updating information about external space under rotation of head and/ or trunk, whereas visual cues, namely the tangent point, help drivers to monitor any deviation from the expected rotation rate of the car. These findings stress another important factor for expecting potential differences in the level of drivers' awareness regarding their perceptual limitations, as a function of driving experience: *their internal spatial representation of driving environment as well as their internal representation of vehicle behaviour*.

Thus, based on the above findings the basic assumption regarding the potential impact of an advanced driver warning system that provides concurrent information regarding to lateral position and time to collision is that, *drivers' reliance on ADAS will be analogous to drivers' awareness of their perceptual limitations on making accurate distance estimations. Therefore,* *drivers' reliance on ADAS will be more evident in relation to TTC information, independently of their experience, while drivers' reliance on ADAS in relation to lateral position will be more evident in novice drivers (less that 1500km).*

8.3 Driver state and learning effects

According to motivational models, namely *"risk homeostasis" theory* (Wilde, 1988; 1982) and *"zero-risk" theory* (Summala, 1988) any intervention into the vehicle or driving environment that does not intend to change drivers' motives will have a limited effect in time, due to behavioural adaptation or an unchanged perceived risk. This means that learning to drive with an advanced warning system without knowing in advance the potential changes that this system will bring about in drivers' motives, there is a certain risk that drivers will adapt their driving behaviour to the opposite extreme of the desired direction.

Furthermore, following Michon's hierarchical structure of the driving task (1985)- first introduced by Allen et al. (1971), according to which driving tasks are classified as: *strategic* (referred to the general planning of the trip such as, trip goals, route, time and speed), *manoeuvring* (referred to the interaction with other traffic and road environment, such as obstacle avoidance, gap acceptance, turning and overtaking) and *operational* (refers to the control of the vehicle and the operation of car controls and pedals), behavioural changes due to integration of the information provided from an advanced warning system, are expected to occur both in strategical and manoeuvring level.

Specifically, at the strategic level a certain distinction should be drawn among those drivers who will use ADAS as a *"reference tool",* either in order to learn to make better estimations or in order to avoid any unwanted effects due to their perceptual limitations (Shinar and Schechtman, 2002), and those drivers who will use ADAS as *a "slave" system* which offers them the opportunity either to allocate their attention to other in-vehicle tasks or to overcome their own limitations and enjoy the "freedom" of driving to the limit (Hoedemaeker, 1999).

These choices on the strategic level would also bear certain consequences in relation to the manoeuvring level. In other words, using ADAS either as a "*reference tool"* or as a *"slave" system,* drivers' safety margins will be different in accordance with their preferred safety margins or their desired level of risk. So the safety margins for those who learn to make better distance estimations will not necessarily coincide with the safety margins of those who just learn to comply with warning indications, in the sense that the latter will be more prone to exceed safety margins in critical traffic situations rather than the former. Along the same line, safety margins for those who take the chance to allocate their attention to secondary tasks will not coincide with safety margins of "sensation seekers" in the sense that the latter will be involved in unsafe acts in critical traffic situations more frequently compared to the former (Figure 2). In other words, "sensation seekers" and "experts" in terms of spatial perception will take the advantage of ADAS to maximize the sensation of pleasure and this will be evident in their overall driving behaviour, whereas "inattentive" and "incapable" drivers in terms of spatial perception will just wait until the exceedness of safety margin happens and this will be evident in critical traffic situations even more.

Changes at maneuvering level		Changes at strategic level	
		ADAS as a reference tool	*ADAS as a "slave" system*
Unsafe acts under Critical traffic situations	High ↑	- Learning to comply with warnings	- Allocating attention to secondary tasks
	Low	- Learning to make better distance estimations	- Driving to the limit

Figure 2 Four possible behavioral changes in both strategic and maneuvering level as a result of behavioral adaptation to Advanced Drivers Assistance System (ADAS).

In summary, different levels of perceptual limitations in distance estimation and different sources of information counteracting those limitations as a function of individual differences and driving experience will have different impact on the level of reliance upon the ADAS information, as well as on the degree of "seeing" ADAS as a co-driver. To validate the proposed behavioural changes we need an evaluation scheme for estimating the ways of integrating ADAS information in long-term.

8.4 Short- and long-term evaluation: how much time is sufficient?

The objective of a longitudinal study within AIDE SP1is to evaluate the long-term effects of the variables in question, in terms of performance changes or even behavioural changes. Time duration of the study is considered as the main factor for having a long-term effect, but how much time is actually needed in order to consider the observed performance as a long-term effect?

A well-known example is an experiment described in Neiser (1976) in which a student practiced for one day each week over a period of six months in reading one text and listening-writing down another one. After six months she was capable of doing these two tasks simultaneously and her performance in terms of errors in comprehension and errors in writing were equally good. But the period of the six months was not a matter of choice, it was simply a matter of coincidence. In other words, if the above mentioned effect would not be evident in six months but earlier (e.g. in four months) or later (e.g. in eight months), the process would have stopped in the fourth month in the first case or it would have continued for another two months in the second case. But performance improvement could not be interpreted differently but as a long-term-effect in either case.

Studying subjects' performance for a long period of time or after a long period of time raises serious methodological questions in regard to the possibility of interpreting or attributing any post-behavioural-effect in terms of one single factor, whereas there are numerous other intervening variables that could explain the post behavioural effect, and these variables are beyond the experimental control. This does not imply that the variables in question are necessarily irrelevant with the observed behavioural change. It pinpoints the very fact, that *we can never be certain that our interpretation is not biased, since the influence of other intervening variables is largely unknown and possibly it will never be unveiled*.

Regarding the long-term evaluation of behavioural adaptation because of using ADAS, the only realistic way to achieve this objective, is to minimize the time duration of the whole study, in order to avoid any unwanted effects either due to the lapse of long-time periods, or due to over-stimulation of subjects in case that they are asked to repeat for a long-period the same route.

8.5 Evaluation Scheme of CERTH/HIT AIDE SP1 study

16 subjects (novice and experienced drivers) will take part in a three phase pilot study over a period of 3 months. The aim of the study is to investigate the short and long-term effects of *advanced drivers' assistance systems, providing time headway and lateral position feedback*, with respect to: (1) longitudinal and lateral "behaviour", (2) speed adaptation and manoeuvring and (3) drivers' mental workload.

During the first phase (Table 3) emphasis will be put on training subjects in each one of the types of information that are provided by those ADAS, by selecting routes that are expected to be more "biased" on TLC instead of TTC and the vice versa (e.g. highways with low traffic vs. rural roads without lines and moderate traffic), with the intent to train subjects in real settings with the ADAS fully in operation.

Behavioural Adaptation Evaluation scheme							
Months		1		2		3	
Week		Short-term		Mid-term		Long-term	
1	A	1½h:	Familiarization	1½ h:	Familiarization	1½ h:	Familiarization
		½ h:	Pre-test trial on distance estimation	½ h:	Pre-test trial on distance estimation	½ h	Pre-test trial on distance estimation
	B					¼ h	Familiarization
						1½ h:	Driving with ADAS fully operated (Route 4)
2	A	¼ h	Familiarization	¼ h	Familiarization	¼ h	Familiarization
		1½ h	Weighted Training in TTC (Route 1)	1½ h	Driving with ADAS fully operated (Route 4)	1½ h:	Driving with ADAS fully operated (Route 4)
	B	¼ h	Familiarization	¼ h	Familiarization	¼ h	Familiarization
		1½ h	Weighted Training in TTC (Route 1)	1½ h	Driving with ADAS fully operated (Route 5)	1½ h:	Driving with ADAS fully operated (Route 4)
						½ h	Post-test trial on distance estimation
3	A	¼ h	Familiarization	¼ h	Familiarization		
		1½ h	Weighted Training in TLC (Route 2)	1½ h	Driving with ADAS fully operated (Route 5)		
	B	¼ h	Familiarization	¼ h	Familiarization		
		1½ h	Weighted Training in TLC (Route 2)	1½ h	Driving with ADAS fully operated (Route 4)		
				½ h	Post-test trial on distance estimation		
4	A	¼ h	Familiarization				
		1½ h	Training in using all information (Route 3)				
	B	¼ h	Familiarization				
		1½ h	Training in using all information (Route 3)				
		½ h	Post-test trial on distance estimation				

Table 3 Evaluation scheme of behavioral adaptation due to Advanced Drivers Assistance System (ADAS).

This process will be repeated twice a week for each subject. More specific during week 2, subjects will drive, after a 15min period of familiarization with the car, for 1_ h in a highway with low traffic (Route 1) at different times. Those driving on Route 1, early in the morning at the beginning of week 2, they will run the same route in early afternoon at the end of the week. Accordingly, during week 3 subjects will drive twice for 1_ h in a rural road with moderate traffic (Route 2), under the same rotation scheme, with the purpose of learning to manage the TLC information. After this period of weighted training in each type of information, during week 4 subjects will drive twice for 1_h in a mixed route (Route 3) with the intent to identify subjects among those using ADAS either as a "*reference tool"* or as a *"slave" system.* This will be achieved by comparing subjects' verbal estimations on vehicle distance from the vehicle in front, lateral position and vehicle speed during week 1, where subjects will drive on Route 3 without having feedback from the ADAS, and during week 4.

During the second and third phase (2nd and 3rd months in correspondence) emphasis will be put on the level of divers' reliance on ADAS information and the way of managing this information under critical traffic conditions. Critical traffic conditions are expected to emerge by selecting a mixed route of urban and rural roads with heavy traffic: Route 4 and 5 (namely, different routes with the same characteristics and traffic demands). In addition and in accordance with the design of a previous field study (Ben-Yaakov et al., 2002), during this phase a small fraction of the information provided will be unreliable by 5%, 20% and 40% and these "malfunctions" will occur at random intervals lasting 30sec. In this way it will be possible to further identify subjects according to a second dimension, namely occurrence of unsafe acts under critical traffic situations.

In general, driver performance will be evaluated in regards to learning effects on distance estimation and the amount of waiting period for exceedness safety margins in critical traffic situations

9 Conclusion

This review of the literature is aimed at identifying the main types of problems that arise in the study of the behavioural adaptation induced by different driver support systems. The review does not necessarily seek to be exhaustive, but rather to highlight the main issues to be taken into consideration before planning the experiments to be conducted during Sub-Project 1 and to identify the most relevant parameters and variables that affect driver behaviour for modelling purposes.

The review is focused in particular on a study of the behavioural effects associated with the use of two types of ADAS (ACC et ISA) and one IVIS (mobile phone), systems for which a sufficient number of empirical studies was available for significant trends to be identified and discussed. The main results of this review of the literature are briefly summarised below:

- Firstly, the review highlighted the *lack of knowledge about learning processes and the long-term effects of driver assistance systems*. It is thus important to develop research into these *temporal aspects* so as to be able to formulate sound recommendations for the design and development of the AIDE system. In particular, it has been stressed that the learning process is crucial for helping drivers to build an appropriate representation of the assistance afforded by the support system and for "calibrating" their trust in it. Research in this area should provide useful information for designing "self-explaining" support systems and for offering drivers additional aids designed to facilitate the learning process. The research planned in AIDE Sub-Project 1 should contribute to our understanding of the learning demands of support systems and their impact on short and long-term behavioural adaptation.

- This review of the literature also concluded that the behavioural effects of support systems seem largely dependent on the situational contexts in which the systems are used. This finding highlights an important dimension to be taken into account in the design and evaluation of support systems, namely the *circumstantial requirements* of driving aids as a function of the dynamics of various environmental conditions and of the driver's motives, objectives and intentions in those conditions. A classification of behavioural effects according to adequate taxonomies of road situations and driving tasks (scenarios of dynamic situation) are needed and would improve our understanding of these circumstantial requirements.

- The issue of the potential *differential impact of the support systems* have been raised and discussed. Some drivers' characteristics such as driving style, locus of control and sensation seeking seems to play a role in the overall frequency of support system usage, the magnitude of some behavioural changes when using the system as well as in the level of acceptance of the assistance provided. However, the relationship between these various individual characteristics are not quite clear and should be clarified.

- At a more general level, our review suggests that there is a need to *clarify the models used for studying behavioural adaptation* (which governs the choice of variables and parameters as well as the interpretation of the results) and for structuring the results with respect to design and safety assessment requirements.

- From a methodological point of view, it also confirms the need to adopt a *multi-level approach* when assessing behavioural adaptation to new driver support systems, which is to say to examine not only the aid's impact on the performance of the specific subtask to which it is dedicated (direct effects) but also its impact on the performance of other driving subtasks (indirect effects). This also entails studying possible changes in the activity of “assisted” drivers as well as in their interactions with other road users. This type of multi-level approach will take precedence in the research to be developed in the next stage of Sub-Project 1.

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Annex 1. Summary of Revised studies - Intelligent speed adaptation systems (ISA)

Study	Saad, F. and Malaterre, G., (1982) La regulation de la vitesse: Analyse des aides au controle de la vitesse (Regulation of speed, an analysis of aides to control the speed, In French), ONSER, France.
Context	Real driving situations Same experimental journeys on rural road (with some built-up area) designed to combine various level of speed limits, road infrastructure characteristics and traffic density.
2.1 Type of mediation	Two speed limiters where the setting of the target (legal) speeds is to be made by the driver himself. A kick-down enables the driver to temporary override the system.
2.2 Method	In-car observation, verbal reports and in-depth interviews. Two type of instructions were given to drivers : a strict instruction (try to set up as often as possible the speed target at the level of the speed limit), a less restrictive instruction (the driver is free to set up the speed target at the level s/he wishes).
2.3 Duration of test	About three hours driving in each study
2.4 Participants	6 men, 6 women in each study, selected according their a priori attitude towards the concept (positive or neutral and negative)
2.5 Studied variables	**Characteristics of the road infrastructure**, traffic density, length and frequency of legal speed variations; **Behaviour indicators**: level of speed target set up, number of use of the kick-down, number of overtaking manoeuvres (successful and aborted), interactions with other car drivers; **Acceptance and perceived utility** according to various road situations

Summary

The first study ever carried out with an in-vehicle system affecting the speed of passenger vehicles was by Saad and Malaterre (1982) in France when they had test persons drive a vehicle where they themselves could set the maximum speed of the vehicle. This speed could not be exceeded unless the driver actively use the kick-down.

The use of the speed limiter depended on the traffic density and the level of the legal speed limits. More traffic led to less use of the speed limiter.

In faster road (with speed limits of 110 and 130 Km/h) involving long stretch of stable driving participants used the speed limiter more frequently.

Most drivers set the maximum speed above the legal speed limits, with the difference being larger when traffic density is high. This enable the driver to adjust to

The findings in this study were that the drivers usually set the maximum speed limit significantly above the legal speed limit so they could adapt to the traffic flow, on faster roads where they could choose speed more freely the difference between their set speed and the speed limit was reduced.

The drivers felt the system was too effective and that their freedom to manoeuvre was limited.

Study	Nilsson, L., Berlin, M. (1992) Driver attitudes and behavioural changes related to presentation of roadside information inside the car. A pilot study of the CAROSI system, VTI-meddelande 689 A, Linköping, Sweden.
Context	Real driving situations
2.1 Type of mediation	Advisory
2.2 Method	In-car observations,
2.3 Duration of test	2x1.5-2 hours, with / without counterbalanced
2.4 Participants	9
2.5 Studied variables	Speed, speed limit obedience, glance frequency
Summary	
In another Swedish field trial, the effects of continuous information on the current speed limit, via a speed limit sign below the speedometer on the dashboard was investigated (Nilsson and Berlin, 1992). The results showed that the average speed was 72 kph with the system and 70 kph without the system, statistically non-significant, but certainly an increase. Speed-limit obedience in a 30 kph school zone was slightly better without the system. The number of glances at the dashboard was on average 3 times higher, while driving with the display as compared to driving without it. It was concluded that the system was ineffective and might increase the accident risk by distracting the driver and speeds increase.	

Study	Persson, H., Towliat, M., Almqvist, S., Risser, R., Magdeburg, M. (1993) Hastighetsbegränsare i bil. Fältstudie av hastigheter, beteenden, konflikter och förarkommentarer vid körning i tätort (Speed-limiters in cars. On-road study on speeds, behaviour, conflicts and drivers comments when driving in built up areas, In Swedish), Lund University, Lund, Sweden.
Context	Real driving situations
2.1 Type of mediation	Mandatory intervention
2.2 Method	In-car observations + instrumented vehicle, without and with the system.
2.3 Duration of test	Familiarization phase (2 x 45 minutes)
2.4 Participants	75 persons randomly selected from the public
2.5 Studied variables	Speed (mean speed and speed at selected spots such as junctions, approaches, corners etc.), car following distance, behaviour towards other road user (yielding).
Summary	
This was the first field study in Sweden, carried out in Lund with 75 drivers from the public in 1992 (Persson et al. 1993). The system consisted of a mandatory speed limiter which was switched on/off manually by an observer in the car. The results showed that mean speed decreased on links by between 2% and 8% with the speed limiter. However, there was a slight tendency to compensate for this by driving faster (by 2-3 kph) through the junctions. There was an increase of the proportion of drivers who kept a correct distance to the car ahead. On the other hand, there was a slight increase of incorrect behaviour towards other road-users at junctions. Most of the drivers generally displayed positive attitudes to the speed limiter, but did sometimes experience feelings of impatience. The most often mentioned advantage for drivers was smoother rhythm in traffic and better awareness for unprotected road-users. The most commonly mentioned disadvantage was not having the acceleration to occasionally exceed speed limits.	

Study	Almqvist, S., Towliat, M. (1993) Aspen track, Estimation of traffic safety benefits by using transmitted road side information to the vehicle, Lund University, Lund, Sweden.
2.1 Type of mediation	Advisory + other systems
Summary	
In 1992, the effects of information on the actual speed limit, on the presence of pedestrians, sharp curves, road works and speed recommendations continuously displayed for the driver were studied (Almqvist and Towliat 1993). The results showed that violations of the speed limits were still frequent when driving with the system.	

Study	Almqvist, S., Nygård M. (1997) Dynamic Speed Adaptation, Field trials with automatic speed adaptation in an urban area, Lund University, Lund, Sweden.
Context	Real driving situations
2.1 Type of mediation	Mandatory intervention
2.2 Observation method	Data recorders & In-car observations
2.3 Duration of test	2 months - Long term effects
2.4 Participants	25
2.5 Studied variables	Speed (mean speed and speed at selected spots such as junctions, approaches, corners etc.), car following distance, behaviour towards other road user (yielding).
Summary	
In a field trial in 1996, 25 passenger cars were equipped with speed limiters for a period of 2 months in a small Swedish town, Eslöv (Almqvist and Nygård, 1997). All approach roads to the town were equipped with radio transmitters (on the 50 kph speed limit signs) which activated the speed limiters of approaching cars and deactivated the speed limiters of those leaving the town. Most of the drivers considered the speed limiter function more positive than they had expected before the field trial. Three of four drivers stated that the limiter induced smoother driving and generally lower speeds. More than half thought that driving became more comfortable with the system. In the before situation (without speed limiter) the speed level was often over the speed limit, while in the after situation the limit could not be exceeded. Observations of driver behaviour indicated improved interactions with other road-users such as improved stopping for pedestrians.	

<table>
<tr><td>Study</td><td>Carsten, O., Comte, S. (1997) UK Work on Automatic Speed Control. Proceedings of the ICTCT 97 conference. 5-7 November 1997, Lund, Sweden.</td></tr>
<tr><td>Context</td><td>Driving simulator</td></tr>
<tr><td>2.1 Type of mediation</td><td>Mandatory intervention</td></tr>
<tr><td>2.2 Observation method</td><td>Measurement of driver performance; Subjective mental workload</td></tr>
<tr><td>2.3 Duration of test</td><td>4 test scenarios in the simulator</td></tr>
<tr><td>2.4 Participants</td><td>15 men, 15 women</td></tr>
<tr><td>2.5 Studied variables</td><td>Approach speed at junctions, speed on curves, traffic light violations, car following, gap acceptance, subjective mental workload</td></tr>
<tr><td colspan="2" align="center">Summary</td></tr>
<tr><td colspan="2">In the UK, Carsten and Comte (1997) conducted experiments in a driving simulator; the research area was Automatic Speed Control in Urban Areas. They found that driver behaviour improved when the speed was limited although a riskier gap acceptance was detected.</td></tr>
</table>

<table>
<tr><td>Study</td><td>Várhelyi, A., Comte, S., Mäkinen, T. (1998) Evaluation of in-car speed limiters – Final report, Deliverable D11 in the MASTER project, VTT, Espoo, Finland</td></tr>
<tr><td>Context</td><td>Driving simulator</td></tr>
<tr><td>2.1 Type of mediation</td><td>Advisory, Limiting intervention, Dynamically limiting intervention</td></tr>
<tr><td>2.2 Observation method</td><td>Measurement of driver performance; Subjective mental workload</td></tr>
<tr><td>2.3 Duration of test</td><td>25 km test-drive, once</td></tr>
<tr><td>2.4 Participants</td><td>60 participants in 4 groups, 1 control and 3 treatment</td></tr>
<tr><td>2.5 Studied variables</td><td>Subjective workload, speed, Time To Collision, overtaking</td></tr>
<tr><td colspan="2" align="center">Summary</td></tr>
<tr><td colspan="2">The University of Leeds Advanced Driving Simulator was used to test two speed control systems against an advisory system and a baseline control (no system).
The speed control systems were both designed to prohibit exceeding the external speed limit; one of the systems additionally applied further speed reduction in hazardous situations, such as sharp horizontal curvature and poor weather conditions.
The advisory system provided information to the driver regarding appropriate speeds via an in-car display. A road environment incorporating urban, rural and motorway scenarios allowed the comparison of the systems across road types.
Driver behaviour under the two control systems was compared to that in the advisory and baseline conditions. Behavioural parameters measured include speed and its derivatives, time headway, overtaking manoeuvres, traffic light violations and collision measures.
Subjective measures of workload were taken to monitor any possible underload or overload effects, and an acceptability questionnaire was administered to ascertain driver opinion about the systems.
Results indicate that there are safety benefits of control systems including a reduction of maximum speed, speed variance and inappropriate speed at hazardous locations. In addition it was found that the advisory system performed well, especially where the driver could perceive the relevance of that information.
However, there were observed secondary effects of the speed control system which may compromise any safety benefits. Such effects included a higher incidence of short time headways, delayed braking and a higher incidence of collisions.
Subjective mental workload scores did not differ between the conditions, but it was shown that drivers found the advisory system more acceptable than the control systems.</td></tr>
</table>

Study	Comte, S., Jamson, H., (1998) The effects of ATT and non-ATT systems and treatments on speed adaptation behaviour, Deliverable D10 in the MASTER project. VTT, Espoo, Finland.
Context	Driving simulator
2.1 Type of mediation	Driver select, Mandatory intervention, Dynamic mandatory intervention
2.2 Observation method	Measurement of driver performance; Subjective and measured mental workload
2.3 Duration of test	Five successive trials, 1 control, 4 experimental, each test drive lasted for 10 minutes
2.4 Participants	30 (15 men 22 – 52 years, avr 32; 15 women 23 – 48 years, avr 30)
2.5 Studied variables	Speed, Curve approach and negotiation, headway, Subjective workload, measured workload
Summary	
MASTER (MAnaging Speeds of Traffic on European Roads) aims to provide recommendations for speed management strategies and policies and develop guidelines for the development of innovative speed management tools. This document reviews the relevant literature and various Advanced Transport Telematics (ATT) and traditional (non-ATT) methods of reducing driver speed are evaluated. It is concluded that traditional methods such as traffic calming can be effective at reducing speed at isolated sites. The most successful measures appear to be those which require drivers physically to lower their speed (e.g road humps) or alter the way in which drivers perceive the road (e.g. perceptual countermeasures). Technologically innovative methods offer opportunities of providing feedback to individual drivers, of implementing variable speed limits to maintain traffic flow and of automating longitudinal control by means of speed limiters and adaptive cruise control. It was concluded that informative or advisory systems may have less potential negative safety effects than intervening systems which automate part of the driving task. The most promising speed management strategies were evaluated in a driving simulator. Drivers encountered curves in a simulated road network that were either treated with one of four implementations or untreated. The four systems employed ranged from information systems (either using traditional methods such as transverse bars, or an in-car advice system), to one which conveyed the threat of punishment (VMS), to a fully automated speed control system. It was hypothesised that by providing information and speed advice to the driver, speed would be reduced on the treated curves. It was also hypothesised that the different systems would have differing effects in terms of their effectiveness. The results suggest that the provision of speed advice to drivers does result in reduced speed on the approach and negotiation to curves. It seems to matter little exactly in what mode this advice is given to drivers. As would be expected optimal performance is attained under an automatic system although further research should evaluate likely long-term benefits and behavioural adaptation issues.	

Study	Brookhuis, K., de Waard, D. (1999) Limiting speed, towards an intelligent speed adapter (ISA), *Transportation Research Part F: Traffic Psychology and Behaviour 2(2): 81-90.*
Context	Real driving situaton
2.1 Type of mediation	Advisory intervention
2.2 Observation method	Measurement of driver performance; Subjective mental workload
2.3 Duration of test	With and without test drive
2.4 Participants	24 (12 control)
2.5 Studied variables	Speed
Summary	
In a Dutch study Brookhuis et al. (1999) tested a system with visual and auditory feedback. They had 24 subjects (12 controls) drive a specified route with an instrumented vehicle. They found that speeds on average were reduced with 4 kph and that the treatment group behaved more according to the traffic rules, in particular speed limits, they further found that speed variance decreased. No significant differences in workload could be found.	

Study	Marell, A., Westin, K. (1999) Intelligent transportation system and traffic safety - drivers perception and acceptance of electronic speed checkers, *Transportation Research Part C*, *1999, 131 -147.*
Context	Out of driving situation
2.1 Type of mediation	Advisory intervention
2.2 Observation method	Questionnaires
2.3 Duration of test	Nine months
2.4 Participants	92
2.5 Studied variables	Acceptance, experience of the system and attitudinal changes
Summary	
At the same time, a trial with an “Electronic Speed Checker” in 92 vehicles for a period of nine months was made in Umeå in 1996 (Marell and Westin, 1999). The system warned the driver with sound and a flashing light when exceeding the speed limit. The results indicated a high acceptance level. The drivers perceived that they had both become more aware of traffic regulations and behaved in accordance with safety regulations. No speed measurements or behavioural observations were however carried out.	

Study	Myhrberg, S., Thunquist, C., Holting, S., Rusk, J., (2000) Försök med elektronisk hastighetsuppföljning i Borlänge. Etapp 2 – Försök med 20 fordon (Trial with electronic speed control in Borlänge. Stage 2 – Trial with 20 vehicles), VBB VIAK, SWECO, Sweden.
Context	Real driving situation
2.1 Type of mediation	Advisory intervention + recording
2.2 Observation method	Data recording
2.3 Duration of test	6 months
2.4 Participants	14
2.5 Studied variables	?
Summary	
In 1997-98 a project, testing ISA as a means for quality assurance in municipal transport services, was carried out in the city of Borlänge (Myhrberg et al., 2000). The aim was to develop technology for speed adaptation for transport services purchased by the municipality and test methods for implementation of the technique. During 6 months, 14 fleet vehicles were equipped with a system consisting of a display informing the driver about the actual speed limit and a warning by beep signal and flashing light when the speed limit was exceeded and a device that registered speeding in a “black box”. The results showed that this technology worked well and it is possible to follow up how the transports were carried out. The drivers seemed to be generally positive to the informative speed adaptation system, but not so enthusiastic by the fact that their speeding was registered. Light signals were experienced by the drivers as less irritating than beep signals, however, they meant that the beep signal had a larger effect for lowering their speed. More than half of the drivers said the system got them to keep the speed limit better.	

Study		Carsten, O., Fowkes, M. (2000) External Vehicle Speed Control. Executive Summary of Project Results. University of Leeds, Leeds, UK.
Context		Driving simulator and on road study
2.1 Type of mediation		Driver select intervention, mandatory intervention & variable mandatory intervention
2.2 Observation method		Measurement of driver performance; Subjective mental workload
2.3 Duration of test	Simulator	4 test drives (1 baseline)
	On-road study	3 test drives á 42 miles (1 baseline)
2.4 Participants	Simulator	40 (10 controls + 3x10 treatment)
	On-road study	24 (8 controls + 2x8 treatment)
2.5 Studied variables	Simulator	Speed, overtaking, gap acceptance tasks, car following
	On-road study	Speed, driving errors, interactions and conflicts, subjective workload
Summary		
Carsten and Fowkes (2000) summarise the results from the External Vehicle Speed Control project (EVSC) which was an extensive study on speed and speed control issues including literature studies on the speed – accident relationship, simulator studies, acceptance studies, modelling and an on road study. Systems tested in this project was a voluntary system called driver select in which the driver himself had the option to decide whether he wanted to be speed-limited or not, a mandatory where the driver always was limited to the speed limit and a variable where the set speed was adjusted for poor road geometry. In the driving simulator they also tested a system with variable speed limits. The interface with the driver was a "dead throttle" and an in car display. The vehicle was also equipped with braking facilities automatically slowing the car down at, for instance, lowered speed limits. In this project they found effects positive for safety in the form of reduced speeds and a decreased propensity to be involved in critical situations and conflicts with the system engaged. The modelling showed reduced fuel consumption and reduced speed variance between the vehicles, but, the travel time increased slightly with the system. Other negative effects that were found were shorter gap acceptance and reduced minimum time to collision. In conclusion they also stressed the importance of observing behaviour in the long-term use.		

Study	Várhelyi, A., Mäkinen, T. (2001) The effects of in-car speed limiters: field studies, *Transportation Research Part C: Emerging Technologies 9(3): 191-211.* (Also in Várhelyi, A., Comte, S., Mäkinen, T. (1998) Evaluation of in-car speed limiters – Final report, Deliverable D11 in the MASTER project, VTT, Espoo, Finland)
Context	Real driving situations
2.1 Type of mediation	Mandatory intervention
2.2 Observation method	Measurement of driver performance
2.3 Duration of test	With and without test drive
2.4 Participants	60 drivers from Spain, Sweden and The UK
2.5 Studied variables	Speed, headway, interactions, approach speeds, turning speeds, give way behaviour, subjective workload
Summary	
Within the framework of an EU-financed project, MASTER, field trials with speed limiters in three European countries: Sweden, the Netherlands and Spain were carried out in 1997 (Várhelyi and Mäkinen, 2001). The results revealed that the speed limiter reduced speeds significantly on roads with speed limits between 30 and 70 kph. On the other hand, no significant changes could be shown on 80 - 90 kph roads and motorways due to heavy traffic. Other positive effects found were: a) decreased speed variance, b) smoother approach speeds at roundabouts, intersections and curves, c) increased time-gaps in the speed interval 30 - 50 kph. No significant effects were found on: a) turning speeds, b) give way behaviour towards pedestrians, cyclists and other cars, c) experienced subjective safety when driving a car equipped with a speed limiter. The indicators of negative effects of the speed limiter were: a) shorter time-gaps in car-following situations on rural roads, b) increased travel time, c) greater frustration and stress, less patience. The main conclusion of the study was that automatic speed limiting by an in-car device is promising within built-up areas where drivers' acceptance of the system is the highest.	

Study	Duynstee, L., Katteler, H., Martens, G. (2001) Intelligent Speed Adaptation: Selected results of the Dutch practical trial, Proceedings of the 8th ITS world congress, Sydney, Australia.
2.1 Type of mediation	Mandatory intervention
2.2 Observation method	Data recording
Summary	
In the city of Tilburg, the Netherlands a 20 vehicle trial with limiting ISA was carried out during 1999 and 2000 (Duynstee et al., 2001). The equipment tested was a version of "dead throttle" and the results showed overall reductions in speed and reduced speed variance. They discovered that mixing ISA vehicles with ordinary vehicles can create some irritation among both ISA drivers and drivers of ordinary cars but relatively few drivers held arguments that should prevent authorities from implementing ISA.	

Study	Lahrmann, H., Runge, J., Boroch, T. (2001) Intelligent Speed Adaptation – Development of a GPS based ISA-system and field trail of the system with 24 test drivers, Aalborg University, Aalborg, Denmark.
2.1 Type of mediation	Advisory intervention
2.2 method	Data recording
Summary	
In Denmark, Lahrmann et al. (2001) tested an advisory intervention system where the intervention consisted of a flashing display, a red LED and a friendly female voice saying for example “50, you are driving too fast” (in Danish). The study showed positive results for adapting the speed and the 85 percentile was reduced by 4-7 kph for the different speed limits.	

Study	Vägverket (2002) Intelligent Speed Adaptation (ISA), Results of large-scale trials in Borlänge, Lidköping, Lund and Umeå during the period 1999-2002. Vägverket publication 2002:89, Borlänge, Sweden.
Context	Real driving situtaions
2.1 Type of mediation	Advisory intervention
2.2 Observation method	Data recorder, measurements in the field, in-car observations, interviews
2.3 Duration of test	Approximately 1 year
2.4 Participants	Approximately 5 000 randomly selected
2.5 Studied variables	Speed (mean speed, turning speed, approach speed), headway, accidents, conflicts
Summary	
This report summarises the experience of the four field-trials carried out in Sweden 199-2002. The systems tested are all advisory intervention systems where one is an Active Accelerator Pedal (AAP) (haptic feedback) and one is an auditory feedback system. The AAP was combined with information on the speed limit while the auditory feedback was both with and without information regarding the speed limit. The purpose of the trial was to test the technology, user acceptance, public acceptance and effectiveness of the various systems. The main behavioural measure in this study was speed in different forms. Between 1999-2002 the Swedish National Road Administration conducted a large-scale trial involving *Intelligent Speed Adaptation* (ISA) in urban areas. Several thousand vehicles were equipped with voluntary, supportive and informative systems to help keep drivers from exceeding the speed limit. Over the three years of the project, the Swedish National Road Administration provided SEK 75 million in funding, and was also responsible for the overall co-ordination of the technology involved, as well as for evaluating the comparative advantages and disadvantages of the various systems. The aim of the trial, which was conducted jointly by the Swedish National Road Administration and four Swedish municipalities, was to learn more about: driver attitudes and how they use the systems the impact on road safety and the environment the integration of the systems in vehicles the prospects for Intelligent Transport Systems (ITS) on a large scale. The systems were tested in Borlänge, Lidköping, Lund and Umeå, where the local authorities were responsible for running the trials in their respective municipalities. 1999 saw the planning of how the trial would be implemented and evaluated, and in 2000 the systems started being installed in the vehicles. Most of the actual field trial was carried out in 2001, when up to 5 000 vehicles, driven by over 10 000 drivers were out in traffic. This means that there are many people who can testify first-hand about what it is like to drive using an ISA system. Numerous surveys and interviews were conducted throughout the trial period. All the data collected trial was compiled and	

analysed in 2002. At the same time, invaluable experience was gained from which to continue discussing the future introduction of ISA on the market.

The main findings were:

Better road safety without increasing travel time

If everyone had ISA, there could be 20% fewer road injuries in urban areas

High acceptance of ISA, and after the trial most test drivers were of the opinion that ISA should be compulsory in urban areas

ISA vehicles were found to have a positive influence on surrounding traffic

Minor differences between the systems, with an average speed reduction of 3-4 km/h on stretches between intersections

The systems must be improved to become more attractive.

Based on the experience from the Swedish ISA project as regards implementation, evaluation, technology, information and the dialogue on the issues involved in a market introduction, the following recommendations can be made as input in the continuation of this dialogue.

The results from the project are clearly positive from a road safety point of view and do not appear to have any essential negative side effects. We therefore strongly recommend that the public and private sectors work in partnership to launch the system on the market as soon as possible.

The Swedish National Road Administration should immediately start drawing up regulations that ISA systems be standard in future vehicles (either as compulsory by law, or through voluntary agreement with the automotive industry). These regulations should be fully drawn up by no later than 2005. In the negotiations with the automotive industry, a decision should be made that the regulations would apply from a specific year (like somewhere between 2008 and 2010) which would give the automotive industry a reasonable amount of time to develop and install ISA systems as a standard feature.

The Swedish National Road Administration should set a good example by having ISA systems installed in its own vehicle fleet by 2005.

In conjunction with this, the speed limit system and surveillance policies must be revised with a view to the new potential provided by ITS.

Study	Hjälmdahl, M., Várhelyi, A. (2004) Speed regulation by In-car active accelerator pedal – Effects on driver behaviour *Transportation Research Part F, In press* (Partly reported in Vägverket, 2002)
Context	Real driving situations
2.1 Type of mediation	Advisory intervention
2.2 Observation method	In-car observations
2.3 Duration of test	Two test-drives (baseline and treatment including a minimum of 6 month customization period in between)
2.4 Participants	28
2.5 Studied variables	Interactions, yielding behaviour, headway, speed adaptation, conflicts, communication
Summary	
The long-term effects of driving with an active accelerator pedal on driver behaviour were studied by using an in-car observation method over the period beginning 2000 until 2001. The system produced a counterforce in the accelerator pedal when the speed limit was reached, but could be overridden by pressing the accelerator pedal harder. Twenty-eight drivers were studied when driving without the system and then when driving with the system after they had used it in their own cars for at least six months. The results showed that their behaviour towards other road users improved, they had a yielding behaviour correct to a higher degree and were more likely to give pedestrians the right of way at zebra crossings when driving with the active accelerator pedal. It was also found that the time gap to the vehicle in front increased slightly with the system. There were also signs of negative behavioural modifications in the form of drivers forgetting to adapt their speed to the speed limit or the prevailing traffic situation when they were not supported by the system and in low speed areas; these effects, however, were not statistically significant. Together with studies showing improved speed behaviour, the results of this study augur well for great safety effects of the system.	

Annex 2: Summary of Revised studies - adaptive cruise control (ACC)

Study	Nilsson, L. (1995). Safety effects of Adaptive Cruise Controls in critical traffic situations. VERTIS (Ed.), Proceedings of the, Second World Congress on Intelligent Transport Systems : *.Steps forward*, Yokohama, 1254-1259.
Context	Driving simulator (moving-base); two lane motorway
2.1 Type of mediation	Supportive ACC controlling throttle and applying “comfortable” braking (2-3 m/s^2); a warning (tone) is given indicating to the driver that he has to take over the system.
2.2 Method	Measurement of driver performance; Scale (NASA-R TLX); Questionnaire : drivers opinions and acceptance
2.3 Duration of test	Familiarisation : not reported; Test : 100 km test drive
2.4 Participants	20 experienced drivers (10 male and 10 female), between 26 and 46 years old. 10 drove with ACC, 10 without
2.5 Studied variables	“**Critical**” **traffic situations** (appearing once each along the route); **Driver behaviour**: speed, time headway, reaction time, maximum braking force, lane occupancy, collisions; **Workload**; **Drivers**’ **Acceptance and opinions**.

Summary

The aims of the study were to investigate effects of ACC use on driver behaviour, acceptance and workload when drivers were exposed to *critical traffic situations*, and to consider the possible impact on traffic safety. Three « critical » traffic situations were studied: 1) Leading car braking hard (no opportunity for the driver to overtake + ACC warning); 2) Pulling out in front the driver ‘s car (driver is about overtaking +ACC warning); 3) Stationary queue (not detected by ACC => no warning).

Results

- **Lane occupancy**: ACC drivers spent significantly more time in the left lane than the drivers without ACC, possibly because of the limited acceleration level. The related risk was probably low on the motorway.
- Critical scenarios:

Scenario 1 : No difference were found between supported and unsupported drivers. Nine of ten ACC drivers waited to take over control until the warning was received. The avoidance manoeuvre was somewhat delayed.

Scenario 2 : All subjects reacted immediately by braking and no difference were found between supported and unsupported drivers. The ACC drivers reacted faster than the ACC and no warning were activated because has already taken over the control.

Scenario 3 : Five collisions were observed during this scenario, four of the colliding drivers were ACC drivers and one was in the control group (not supported). No warning were given when the situation turned out to be critical. For supported drivers, a reasonable explanation is that they detected the vehicle ahead, and expected the ACC to perform the control as usual.

Workload : both driving conditions (with and without ACC) imposed a moderate load.

Drivers’ opinions : Drivers has a positive attitude towards ACC and they found it usable. They also seem to trust the system and rated it very easy to learn and to operate. However they considered that ACC did not behave completely as themselves.

Conclusion. The use of the studied ACC influenced driver behaviour differently in the various « critical » scenarios. Approaching a stationary queue lead to more collisions among ACC-drivers than among unsupported drivers, however, the collisions could neither be explained by increased driver workload nor by decreased level of alertness. It seems reasonable that driver knowing that they were supported would expect more the system than it can provide. Even drivers who have been informed about ACC limitations may problems to identify situations requiring them to take over control, at least in time to avoid the development of critical situations or in worst case accidents.

Study	Ward, N. J., Fairclough S., Humphreys, M. (1995). The Effect of Task Automatisation in the Automotive Context: A Field Study of an Autonomous Intelligent Cruise Control System. In D.J. Garland & M.R. Endsley (Eds), Experimental Analysis and Measurements of Situational Awareness. Embry-Riddle Aeronautical University Press, Daytona Beach, Florida, USA, 369-374.
Context	Real driving situation on a major highway
2.1 Type of mediation	AICC
2. Method	Instrumented car (data recording), scales and questionnaires
2.3 Duration of test	1/2 H training session + 2 "1/2 H driving sessions" (with and without AICC)
2.4 Participants	15 male drivers, with experience on conventional cruise control systems. Average age: 39; Annual mileage reported: 12500 miles; divided into 2 groups : high and low sensation seekers
2.5 Studied variables and measurement	**Characteristics of the driver**: sensation seeking (SS Scale); **Driver performance**: speed, time headway, lane position; **Situation Awareness** : Reaction time, self-report questionnaire, frequency of driving errors; **Comfort**: Affective state and level of arousal : (UMACL); **Level of arousal**: Modified Stanford Sleepiness Scale (M-SSS); **Mental workload** (NASA R-TLX)
Summary	
This study examined the effect of AICC on driver comfort and driving behaviour. A sample of 15 male participants was divided into 2 groups of high and low sensation seekers. Subjects drove a set route along a highway in moderate traffic with and without a prototype AICC system. The study comprised a mixed 2 (AICC: AICC vs. Non-AICC) within 2 (SS: HSS vs. LSS) between subject factor design, and the order of the driving sessions was counterbalanced (AICC, non-AICC). UMACL and M-SSS were administered before the first session in order to obtain baseline measures of mood and arousal. After each session, the UMACL, M-SSS and NASA R-TLX were administered to drivers. The experimenter recorded the frequency of driving errors during each session in order to evaluate driver's Situation Awareness. Results : **Mental workload**. The only significant effect of AICC on mental workload emerged as a significant interaction with SS for the effort item. Reported effort in maintaining adequate speed and headway was significantly less with AICC than without, only for the HSS group. **Level of arousal**. Drivers reported lower level of energy and activation with AICC than without. **Affective state.** HSS group reported less tense arousal with AICC than did the LSS group, and without AICC. **Situation awareness** (assessed on the basis of "driving errors"). There was some evidence that poor attention to lane positioning with AICC; Failure to yield to other traffic was more frequent with AICC; Distraction : drivers were more often distracted with AICC than without. Drivers were observed significantly less often to follow too closely with AICC than without; Finally, there was a significant interaction between SS and AICC for episodes of excessive speed. The HSS group were observed speeding significantly less often with AICC than without. **Vehicle and system operation** (data filtered to only include recordings taken whilst the system was operating). Set speed and TH in the AICC session were compared to driven speed and TH in the non-AICC session. HSS group adopted (either set or driven) higher speeds than the LSS group. Drivers set higher average speed with AICC than they drove without AICC. The drivers varied the setting of their speed less often with AICC than they varied their driven speed without AICC. Drivers set shorter headway with AICC than they drove at without AICC.	

Study	Nilsson, L. and Nåbo, A. (1996) Evaluation of application 3: Intelligent cruise control simulator experiment. VTI särtryck No 266. VTI. Linköping. Sweden
Context	Driving simulator (moving-base)
2.1 Type of mediation	Intelligent Cruise Control (ICC): Automatic (speed and headway was controlled automatically), informative (advise on speed and headway was given).
2.2 Methods	Data recording of driver behaviour, scales and questionnaires secondary task, scale (subjective workload)
2.3 Duration of test	80 km test drive
2.4 Participants	30 men, 30 women; “young” (less than 60 yr old) and “experienced” (license age of at least 5 yr and 10 000km driving/yr, randomly assigned to six experimental conditions
2.5 Studied variables	**Driving performance**: Speed, lateral position, time headway and reaction time; **Answers on a communication task** (phone call); **Subjective workload**

Summary

Six experimental conditions were tested: automatic ICC, Info ICC and control, in addition these conditions were combined with or without a telephone task.

Speed level. Auto ICC resulted on average in a 3 km/h higher speed than the Info ICC and 0.9 km/h higher than the control speed, the mobile phone task resulted in a 1.4 km/h reduction in speed level for the three conditions.

Speed variability was significantly influenced by the ICC mode where the Auto ICC led to a decreased variation in speed, both compared to the info ICC and control. The telephone task did not show any effect on speed variability.

Lateral position. no effect could be found on lateral position.

Reaction times. Reaction times were longer when using the ICC systems, however, when combined with the telephone task the reaction times were reduced when driving with ICC systems compared to the control.

Car following. It was found that the subjects kept a longer distance to the vehicle in front when supported by the informative ICC than for the automatic ICC and control, probably because the drivers kept a distance and some margin so that they would not receive any warnings. Telephone use did not show any effect for any of the tested conditions.

Curve negotiating : For curve negotiating the highest speed was obtained when the automatic ICC was used and the lowest speed was kept when the informative ICC was used, both for sharp curves and longer curves. The telephone task reduced speed for all the conditions.

Passing sections with reduced speed limit. For the informative ICC the speed was reduced to a higher degree when passing the reduced speed sign. Surprisingly the speed was the highest for the automatic ICC and this was probably due to a wrong setting in the control algorithm. There was no difference in mean speed when the telephone task was performed but there was a significantly higher speed variation for the informative ICC and the control condition.

Workload. The only factor where there was a significant difference of the ICC-systems was the mental demand where there was an increase for the informative ICC. For the telephone task there was an increase for mental demand, time pressure, effort and frustration while there was a decrease in performance. There were also significant increases for the combination of an ICC and telephone in frustration and effort.

Conclusion. Use of the informative ICC resulted in longer headways and lower speed levels than use of the automatic ICC. Speed and headway variability was reduced, but only by the automatic ICC. The automatic ICC prevented the shortest headways appearing. Use of informative ICC imposed higher mental demand on the drivers than use of the automatic ICC.

Study	Saad, F. & Villame, T. (1996). Assessing new driving support systems : contribution of an analysis of drivers' activity in real situations. In Proceedings of Third Annual World Congress on Intelligent Transport Systems (CD-Rom).
Context	Real driving situation. Two and three lane Motorway sections + outside of peak hours
2.1 Type of mediation	AICC (no braking + warning to take over).
2.2 Method	Instrumented car (data recording + video recording), verbal report and interviews
2.3 Duration of test	Familiarisation: Two hours driving in real driving situation Driving : One hour driving without ACC and Two hours driving with ACC
2.4 Participants	9 experienced drivers (5 men and 4 women).
2.5 Studied variables	**Driver behaviour**: speed, time headway, lane occupancy, number of lane change manoeuvre (pulling in and pulling out), number of vehicle overtaken; **Road situations**: traffic constraints (three levels), road infrastructure characteristics (two or three lanes motorway sections), manoeuvres carried out by other drivers (cutting-in and pulling out); number of vehicles overtaking the driver.

Summary

The aim of this research work was to highlight the way in which experienced drivers integrate in their driving activity the assistance provided by an AICC system. The analysis was focused more particularly on drivers' strategies in “normal” driving and “assisted” driving when undertaking a motorway journey.

Results

Drivers’ behaviour over the whole journey (70 km with and 70 km without AICC). There was no significant difference in the average speeds with and without AICC. There was an reduction in the average number of manoeuvres performed by drivers when driving with ACC, associated with an increase in time spent in the left-hand lane. Lastly, there was a reduction in the frequency of “critical” safety margins in car-following situations (time headway: ≤ 1 second) when driving with AICC. Changes in behaviour seem to depend on the “drivers’ driving style”. In particular, reduction in the number of lane change manoeuvres is primarily observed within the group of drivers who usually tend to change lane frequently in their usual driving. Overall, driving with ACC had the effect of making driving behaviour more “homogeneous”.

Drivers' strategies when performing lane-change manoeuvres. The effect of three variables were studied, the driving conditions (with or without ACC), the type of manoeuvre performed (pulling out or pulling in), and the level of traffic constraint, on speed (N=755) and on Time headway in car-following situations (N=423) prior to a lane change. No difference was observed in speeds when driving with and without AICC. On the other hand, time headways were significantly greater when driving with ACC. It has to be pointed out, however, that these changes in strategy depend on the *type* of *manoeuvre performed and of traffic density*. When driving with AICC, drivers adopted larger headways when pulling out whereas the difference is not significant when pulling in Time headways in average-density traffic increased significantly when driving with AICC, whereas that is not the case when the traffic constraint is stronger.

Conclusion. The results highlighted the importance of situational variables with regard to the control modes used by drivers in their current driving practice and when driving with AICC. They confirmed the need to take into account several dimensions of the drivers' behaviour to analyse adaptations to the new system. Drivers’ strategies when using AICC are seen as enable them to take advantage of the regulation it affords and to avoid having to vary their speed too often or to keep having to resort to “manual override” in situations where they think they “will not agree” with the regulating action taken by the system (slowing them down before overtaking, for instance).

Study	Ward, N. J., Humphreys M., Fairclough S. (1996). A field study of behavioural adaptation with an autonomous intelligent cruise control system. In Handbook of the International Conference on Traffic and Transport Psychology, 22-25 May, Valencia, Spain, 15-19.
2.1 Type of mediation	AICC
2.2 Method	Instrumented car; scales (Sensation Seeking,) and questionnaire (perceived risk)
Context	On road study on a major highway
2.3 Duration of test	1/2 H training session + 2 “1/2 H driving sessions” (with and without AICC)
2.4 Participants	15 male drivers, with experience on conventional cruise control systems. Average age: 39; Annual mileage reported: 12500 miles; having experience with conventional CC. Drivers were divided into 2 groups : high and low sensation seekers
2.5 Studied variables	Characteristics of the drivers: sensation seeking; Perceived risk; Driving performance: speed, time headway.
Summary	
This study investigates the effects of AICC on driver perceptions and driver behaviour. The analysis of AICC data presented in this paper focuses only on the data recorded when the AICC system is operating. Speed was calculated when the system was functioning in the cruise mode (approximately 46,8 % of AICC trial time) and headway was calculated when the system was in the “following mode” (approximately 42 % of AICC trial time). Data for the Without AICC session were calculated for the entire period. Results : **Perceived Risk**. High sensation seekers perceived the system to increase safety more than LSS. **Mean speed and speed variation**. Participants drove with a faster average speed with AICC than without. HSS drivers drove with a faster average speed than the LSS group. However, speed variation is reduced when driving with AICC. **Maximum speed**. Drivers adopted a *slower* maximum speed with AICC than without. HSS drivers drove with a faster maximum speed than the LSS group. **Mean Time headway and variation.** There was a tendency for participants to drive with a shorter average TH with AICC than without, but this effect is not significant. Participants were less variable in driving with AICC than without. HSS drivers drove with less variation in TH than the LSS drivers. **Minimum Time headway**. Participants drove with a *larger minimum* TH with AICC than without. There was a tendency for HSS drivers to drive with a larger minimum TH than the LSS drivers. **Conclusion.** The use of AICC can result in a degree of behavioural adaptation. The AICC system was perceived by participants to increase safety, particularly by HSS. This perception may be based on the significant reduction in variation and extreme values in speed and headway with AICC. On the basis of the presumed reduction in risk perception, the system was used to drive at average faster speeds. In the “following” mode of AICC, shorter headway distances were also evident. It would appear that any safety benefit was subsumed by a motive to enhance mobility through increased speed. This pattern of behavioural adaptation may induce no net safety advantage. However, some safety benefit may be realised by the significant reduction in variation in vehicle operation parameters resulting in less extreme speed and headway values.	

Study	Kopf, M., and Nirschl, G. (1997). Driver-vehicle interaction while driving with ACC in borderline situations. In Proceedings of the 4th World Congress on ITS. Berlin, Germany.
Context	Real driving situations Motorways
2.1 Type of mediation	Three versions of ACC (combination of different levels of deceleration - soft, medium and hard- and set time headway -2.1s, 1.8s, 1.5s-).
2.2 Method	Instrumented car + Video records + Reproducible take over situations created by a second experimental car; Drivers' verbal comments after each situations (concerning risk, controllability and predictability). Questionnaires, after each ride
2.3 Duration of test	Five rides , 130km/1,25 h long : **Ride 1 and 2**: Training phase (driver were free in their manoeuvring behaviour); **Ride 3 and 4**: Experimental phase (driver were instructed to follow the recommendations of the experimenter, reproducible situations: Following/brake situations and Approach situations. **Ride 5**: opportunity for drivers to try the other versions of ACC
2.4 Participants	13 participants, rated with respect to their driving behaviour (careful, medium and sportive)
2.5 Studied variables	**Characteristics of ACC**: three versions. **Learning**; **Driver performance and strategy:** Frequency of drivers' braking actions, driver intervention strategy; **Stress / Strain**: secondary task

Summary

This paper presents an interaction model for the driver-vehicle-environment loop and seek to clarify the term of « subjective borderline situations ». In addition, the reasons for occurrence of borderline situations are outlined. Then, an experiment in real driving situation is described in which three version of ACC (differing mainly in the maximum deceleration which could be applied by the system) were tested. The borderline situations evoked in the experiment are defined as « caused by a discrepancy between the internal model of the ACC system and its real behaviour ».

The first aim of the experiment was to find out how drivers learn the system behaviour and how they react in various situations corresponding to their learning state. The second aim was to examine acceptance, risk perception and subjective predictability with respect to the different ACC systems. Participants were brought to situations where either the ACC or themselves has to act by braking or decelerating to keep a safe distance to the preceding vehicle (second experimental car in front of the ACC car).

Results.

The ACC system feature to be learned in the experiment was the dynamic behaviour in approach situations. The results suggest that the drivers are able to predict this behaviour. They predict the distance and intervene if a personal safety margin threatens to be exceeded. Intervention frequencies and workload decrease with increasing experience.

The results also shows that a different layout of ACC parameters influences driver behaviour with respect to learning and mental workload. One version of ACC, requiring most difficult decision making, results in the highest mental workload.

Conclusion. The challenge for the future is to find means *to accelerate the learning process*. As the system behaviour prediction plays a major role in the driver vehicle interaction, its seems sensible to assist the driver with a special display supporting his prediction capabilities. As it is known that system behaviour prediction plays a major role in the driver-vehicle interaction it seems sensible to assist the driver with a special display supporting his prediction capabilities. This could be, for example, a specific sound indicating that the ACC system had recognised a relevant object and will brake immediately.

Study	Stanton, N. A., Young, M., & McCaulder, B. (1997). Drive-by-wire: the case of driver workload and reclaiming control with adaptive cruise control. Safety Science, 27, 2/3, 149–159.
Context	Driving simulator (fixed base)
2.1 Type of mediation	ACC
2.2 Method	Measurement of driver performance; performance to a secondary task.
2.3 Duration of test	Not reported
2.4 Participants	12 (6 male and six female drivers) with a mean age of 21 years; holding full driving licences for an average of 3.4 years.
2.5 Studied variables	**Driving performance**: Lateral position, distance headway, accelerator input, brake input; **Reclaiming control in one critical traffic situation**; **Attentional capacity**: performance to a secondary task.

Summary

The study investigates the workload demanded by the driving task in manual and automated scenarios. In addition, the automated condition was designed to present a failure situation in ACC operation which requires the driver to reclaim manual control of the vehicle.

Results

Driver behaviour. The results show that there were no significant differences in driver behaviour in the automated and manual condition with respect to the position of the vehicle on the road**,** distance from the lead vehicle and speed of the vehicle.

Workload. The secondary task showed significant differences between the manual and automated conditions with significantly more items being correctly identified by participants in the automated condition.

Reclaiming control. four of the twelve participants failed to reclaim control of the vehicle in an effective manner before it crashed into the lead vehicle. However, eight of the participants did respond effectively. Two participants steered out and six participants employed the strategies of steering and braking together.

Conclusion. Automation at some level does reduce driver workload and performance is degraded in a critical situation. The link between the level of attention of drivers and their ability to reclaim control needs to be explored further.

Study	Fancher P., Ervin R. and Bogard S. (1998). A field operational test of adaptive cruise control: System operability in naturalistic use. In: Proceedings of the Society of Automotive Engineers International Congress and Exposition, SAE Technical Paper No. 980852, Special Publication SP- 1332, Detroit, MI.
Context	Real driving situations
2.1 Type of mediation	ACC
2.2 Method	Data recording of driver behaviour Focus group and Questionnaires
2.3 Duration of test	Between two and five weeks of usage
2.4 Participants	108
2.5 Studied variables	**Driver performance** and behaviour: Speed, Time headway, braking, etc. use of ACC; Acceptance

Summary

This is a huge field trial with many relevant levels of data analysis and results. It is not possible to present in detail the various analyses performed in this study (see Final Report 1998). We take as a basis the summary the authors provide in the paper given in reference above.

Results

ACC use. Drivers chose to use the ACC frequently, especially when traveling in the higher speed range and when traffic densities were moderate. The system utilisation actually reveals a great deal about the participants' judgment of suitability in the provided ACC function, given the actually prevailing driving conditions. « Conditions » here apply to at least 1) on the individual's own driving style, 2) the road type, 3) the prevailing traffic density, 4) the trip length. Speed (which co-varies with road type and traffic conditions) strogly determine the level of utilisation.

Time headway. Use of ACC reduces the frequency of short TH compared to that observed in manual driving. The ACC acts to ensure somewhat greater value of time headway, thereby making the driving task more comfortable. The choice of TH setting in ACC driving is closely related to the individuals' age and « driving style ».

Drivers assessment of ACC use. ACC is perceived as rather *easy to use*, *quick to learn*, satisfying in its use, and more or less straight forward to supervise in the hand of most lay drivers.

Conclusion.

Study	Hoedemaeker M., Brookhuis K.A. (1998) Behavioural adaptation to driving with an adaptive cruise control (ACC). *Transportation Research,* Part F,1, 95-106
Context	Driving simulator (fixed-base); A standard highway route of two lanes in two direction. Several different traffic scenarios :
2.1 Type of mediation	ACC
2.2 Method	Measurement of driver performance; Acceptability questionnaire (perceived usefulness and perceived comfort); Mental effort scale (RSME)
2.3 Duration of test	Not reported
2.4 Participants	38 (25 male, 13 female, between 25 and 60 years old), Selected on the basis of driving experience and answer on the DSQ (Driving Style questionnaire)
2.5 Studied variables	**Characteristics of the drivers**: Driving style; **Characteristics of ACC**: different TH parameters (preferred; 1.5 and 1.0s) possibility or not to overrule the system; **Traffic scenarios**: busy and quiet trafffic; queue driving; merging into left lane and an emergency stop when driving in a platoon or a traffic queue; **Driver performance**: speed, time headway (minimum), brake force, lateral position; **Mental effort**

Summary

The aim of the study was to assess driver behaviour response to ACC systems as a function of driving style. The four groups of participants taking part to the experiment differed on reported driving styles concerning Speed (driving fast) and Focus (the ability to ignore distractions).

Results

Driving behaviour.

Speed. In quiet traffic, average speed was higher when driving with ACC. The driving style groups differed significantly in their speeds but no interaction between group and ACC were found.

Lane occupancy. With ACC, drivers spent more time on the left lane. The speed groups differed in left lane occupancy.

Lateral position on the road. The standard deviation of the lateral position increased when driving with ACC. No significant interaction with driver group was found.

Merging manoeuvres. They are carried out more efficiently with ACC;

Emergency stop scenario. The average maximum braking was larger with ACC and the average minimum TH was smaller.

Mental Workload and acceptance.

The participants experienced driving with ACC as less effortful than driving without. The slower driving groups perceived ACC as more comfortable and more useful than the fast driving groups. Drivers had no preference for one of the TH parameters. All participants perceived the ACC system that could be over-ruled as more comfortable and more useful.

Conclusion. All drivers adapt their behaviour with respect to speed, irrespective of their driving style. On average, they adopted smaller time headway and merging manoeuvres were carried out more efficiently with ACC. Interaction effects between driving style group and behaviour with or without ACC were found on minimum TH and maximum braking level. Minimum TH adopted by low speed drivers decreased more with ACC than it did for the high-speed drivers. Drivers who like to drive fast are less positive about ACC with respect to both perceived comfort and perceived usefulness. Results show behavioural adaptation with an ACC in terms of higher speed, smaller minimum time headway and larger brake force.

Study	McLaughlin S., Serafin C. (1999). Measurement of Driver Intervention Responses During Transition from ACC Deceleration to Manual Control. In Proceedings of the ITS, America conference, Washington, DC, USA.
Context	Real driving situation
2.1 Type of mediation	ACC
2.2 Method	Instrumented car (data recording + video recording), debriefing, questionnaires
2.3 Duration of test	Initial baseline driving (no ACC) + ACC demonstration; 13 trials with various successful ACC decelerations; 14th trial with an insufficient ACC deceleration.
2.4 Participants	10 males and 10 female drivers : 2 age groups (21-30 years, and 40-50 years), more than 2 years driving experience; all using conventional cruise control on highways.
2.5 Studied variables	**Characteristics of the driver**: Age, Gender; **Driver performance when taking over**: foot position, and foot movement time; Time-to-collision (TTC) and time headway; manual (intervention) braking profile.

Summary

An experiment was conducted in order to evaluate driver intervention during an adaptive cruise control deceleration behind a lead vehicle. Its objective was to investigate the timing and nature of an ACC user's response and manual control of deceleration when intervention is required.

Results

During the presentation of the 14th trial, the driver response to the situation was recorded for analysis. The result are given in detail in the paper according to three main stages for driver intervention. Only the main results are summarised below.

Before brake pedal contact While approaching the slower moving vehicle, drivers began moving towards the brake between 16.1s and 0.8s prior to activating the brake pedal. The TTC at the time of motion towards the brake pedal ranged from 4s to 21s and the TTC median was 7.4s.

At brake pedal contact. TTC upon brake activation ranged from 6.1 s to 3.7 s. and the mean TTC was 4.4s. The older age group intervened (braked) later than the younger age group (4.1s vs 4.8s). TH for the intervention ranged from 0.7s to 1.3s and the mean TH was 0.9s. The mean TH is shorter for the older group than the younger group (0.8s vs 1.0s).

After brake pedal contact. Minimum TTC during the approach of the lead vehicle range from 5.9s s to 2.3s and the mean minimum TTC was 3.9S. No significant difference was between the driver groups.

Conclusion. From observation and participant comments, presentation of the intervention scenario seemed to successfully generate an intervention from the driver. The participants had accustomed to the ACC vehicle handling the decelerations. So their responses, including their initial resting foot position, movement toward the pedal, and covering (maintaining a foot position that permits activation of the brake) while evaluating the need to intervene, are considered indicative of what could be expected during actual use of the system. The finding that *older drivers intervened later than younger drivers* can be interpreted as being due to slower response times for older drivers, greater trust for the system, or a later perception of exceeding some threshold.

Study	Hoedemaeker, M. & Kopf, M. (2001). Visual sampling behaviour when driving with adaptive cruise control. In Vision in vehicle Conference 9.
Context	Real driving situation
2.1 Type of mediation	ACC with 3 modes : Assistance mode: the system gives feedback to the driver by mean of an active accelerator pedal. The return force in the pedal indicates the required action on the accelerator, so the driver is required to keep his foot on the accelerator pedal. Automatic mode without braking: the system takes over the longitudinal task of the driver. After activating the ACC, the driver can release his foot from the accelerator pedal. (induced decelerationabout 0.5 m^2/s). Automatic mode with braking: The maximum deceleration level is set to 1.5 m^2/s.
2.2 Method	Instrumented car, central vision occlusion technique, questionnaires and scale (NASA-TLX)
2.3 Duration of test	Not reported
2.4 Participants	24 experienced males, age from 25 to 40
2.5 Studied variables	**ACC mode**; **visual attention; traffic situation** (deceleration or car following). **Driver performance**: speed, headway, time-to-collision, deceleration overshoot (maximum deceleration of the test car divided by the acceleration of the lead car), **mental workload**, **acceptance**.

Summary

The objective of this study was to test the effects of 3 different Adaptive Cruise Control systems on visual sampling behaviour in an on-the-road experiment. 3 groups of 8 subjects drove a vehicle test equipped with an ACC system, and had to follow a lead car which decelerated randomly in time (4 times during the test). Drivers practised with the ACC, with the lead car in front of them performing deceleration manoeuvres and also got also acquainted to the occlusion system. The drivers were then instructed to follow the lead car at particular speed and headway values. The lead car decelerated 4 times during the test, some of which requiring the driver intervention. Participants drove half of the trial with and half without the central occlusion glasses.

Results

Visual attention. The occlusion time Increases when driving with an ACC, but this increase is much stronger in the car following situation than in the deceleration situation. When driving with one observes a decrease of glace frequency. Driving with automatic ACC hard braking leads to the largest decrease in glance frequency. Driving with ACC reduces visual workload.

Speed and headway. On average speed decreases when driving with ACC and no effect of ACC on headway.

Time-to-collision when the driver decide to brake (deceleration situations). Without ACC, TTC is larger than with ACC (37s vs 25s).

Subjective workload. When driving with the Assisting ACC average mental workload increases compared to driving without ACC, but when driving in both Automatic modes of the ACC mental workload decreases.

Acceptance. Drivers perceive driving with an ACC as more useful and comfortable than driving without. The comfort does not increase when driving with the Assisting ACC compared to driving without. It only increases when driving with the automatic ACC, especially the aumatic braking ACC.

Conclusion. ACC reduces visual workload associated with the longitudinal control task during car following situations. This reduction is more pronounced in the Automatic ACC mode with braking. In situations with a decelerating lead car, visual workload is comparable to driving without ACC. In these situations drivers might have to overrule the system. But this overruling is always performed adequately.

Study	Kopf, M. & Simon, J. (2001). A Concept for a Learn-Adaptive Advanced Driver Assistance System. Conference on Cognitive Science Approaches 2001, Neubiberg, September. .
Context	Real driving situation
2.1 Type of mediation	ACC
2.2 method	Instrumented car, semi-structured interviews and questionnaires
2.3 Duration of test	2,5 weeks driving (on average 3,500 Km)
2.4 Participants	5 participants aged between 28-55
2.5 Studied variables	**ACC usage**: average amount of times the ACC was ON per km and changes over time; **Modes of taking over situations**: hard braking, turning off the system via a moderate braking and switching off the system via the on/off button and changes over time.

Summary

This paper presents a conceptualisation of a « learn-adaptive, self explaining » Advanced Driver Assistance System. An extensive analysis of long term drivers' interactions with an ACC system was carried out in order to answer the following key questions: When (in what situation) and how is the ACC system used after extended usage? How do people learn the system capabilities and limits ? How does the discovery of limits of the system affect future operational use and driver behaviour ?

Results

In depth analysis of the drivers' usage of the ACC system revealed stages of use hindered by three main problematic areas: the operational use of the system; system limits; use of the system in particular environment conditions (i.e.; type of road or adverse driving conditions, poor visibility, snow and fog).

Change over time of ACC usage. the results suggest different stages in system usage : a preliminary stage of getting to know the system (learning to operate it), a testing phase (learning the system limits) and a familiarisation stage (learning to use the system appropriately in particular environments).

Take-over situations. An analysis of driver intervention by *hard braking* over time suggests that there was a trend towards testing the limits of the system at the beginning, followed by a certain apprehension of the system capabilities and then a more personalised "steady usage" of the system. *Switching off the system* via the on/off button increases as the drivers' ability to predict situations increases for 3 drivers out of 5.

Conclusion. On the basis of the analysis of drivers' usage of the system, two help systems are suggested to help drivers develop appropriate conceptualisations of the system's behaviour and reduce the learning time before steady usage is achieved.

Study	Weinberger, M., Winner, H. and Bubb, H. (2001). Adaptive cruise control Field operational test - the learning phase. *JSAE Review*, 22, 487–494.
Context	Real driving conditions
2.1Type of mediation	ACC
2.2 Method	Instrumented vehicles during “normal use” of ACC (four weeks) and instrumented vehicle (+ video recording) during Test drives (five times). Questionnaires about the use of the system (administrated 5 times) + Interviews
2.3 Duration of test	Four weeks
2.4 Participants	15 male drivers; driving about 1000 km per week; used to drive the same type as the test vehicles.
2.5 Studied variables	Familiarity with the operation of ACC; Ability to judge take over situations; Behaviour: TTC linked to take over situations.

Summary

The paper presented the results of a long-term field operational test during which 15 participants used an ACC equipped car over a period of four weeks each. During the test phase, different methods were used for data acquisition: questionnaires and interviews as well as objective data about driver interventions during the ACC usage were analysed with respect to the duration of the learning phase.

Main results

Operation controls and display. The participants’ answers to the questionnaires shows that they felt familiar with the operation of ACC after a period of about two weeks.

Take over situations.

Interview and questionnaire. The majority of the participants estimated that the duration of the learning phase is about 2 weeks. After this phase, they felt that the driving situations in relation to the ACC’ functional limitations, concerning braking and detection range. Concerning two take-over situations, approaching a slower vehicle and following another vehcile which decelerates strongly, the participants felt to have made great progress in their ability to juge approaching a slower vehicle in the third week of the field test and in the second week for situations where the leading vehicle is decelerating.

Test drives.

The results of an analysis of take over situations during the test drives (N=569) indicate show significant changes of the minimum distance between the ACC vehicle and the lead vehicle. The most important changes in driver behaviour happened during the first two weeh of ACC usage.

Long term drives. One observes that the ACC system very often begins to decelerate before the driver decides to intervene. The analysis of the average value of TTC at driver intervention also suggests than most of the learning process is completed afetr the first two weeks.

Conclusions. Two or three weeks are needed to learn the operation of ACC and the assessment of take over situations. **Note**: the authors stress the fact that the participants in this study drove about 1400 km per week (much more than the average German driver, who drives about 270km per week). Thus other ACC users might take a different learning time.

Study	Törnros, J., Nilsson, L., Kircher, A. (2002). Effects of ACC on driver behaviour, workload and acceptance in relation to minimum time headway. In Proceedings of the 9th World Congress on Intelligent Transport Systems ITS. (**Major study**)
Context	Driving simulator (Moving base); Two rural road sections (one lane in each direction, speed limit 90km/h) and Two motorway sections (speed limit 110km/h)
2.1 Type of mediation	ACC with
2.2 Method	Measurement of behavioural indicators, scales and questionnaires (NASA-TLX, User acceptance, usefulness and satisfaction, usability)
2.3 Duration of test	Familiarisation: 20 km in order to familiarise with the simulator, the driving task and the ACC. The participant was instructed to use the ACC and test its function. Test: 4 test drives, ACC/No ACC & Rural road/Motorway counterbalanced; The participant was instructed to reconnect ACC every time it had been disconnected.
2.4 Participants	24 participants (12 male, 12 female); age: 23-55 years (average 40), with a driving licence for 5-37 years (average 19)
Variables studied	**Driving situations or scenarios**: « normal » and « critical » driving situations; 6 different test scenarios were presented in motorway sections and 5 in rural roads sections Scenarios included approaching other cars and traffic queues, and overtaking cars at various speeds. **Type of road**: motorway and rural roads, **Driver performance:** Speed, lateral position, left lane driving, overtaking behaviour, time to collision (TTC)**; Workload, acceptance, usability.**

Summary

The aim of this study was to evaluate an ACC system with respect to the following traffic safety related aspects: driving behaviour, task demand (workload), user acceptance and usability. Interactions with ACC minimum time headway were also analysed.

Results :

Effect of ACC support on general driving behaviour

Speed : the maximum driving speed was reduced when there was no traffic around. ***Lateral position*** (when no other traffic was present): neither mean lateral position nor standard deviation of lateral position was affected by ACC. ***Lane occupancy*** : the distance spent in the left lane increased as an effect of ACC when driving on the motorway, whereas no such effect appeared on the rural road.

Effect of ACC support on driving behaviour at interactions with other cars

Distance from car ahead when overtaking. Studied in five scenarios, only on motorway driving. No significant differences were found for any of the scenarios. ***Minimum TTC***. Studied for most scenarios. Minimum TTC was shorter with ACC tan without. Minimum time to collision was reduced with ACC for 2 *non-critical scenarios* on the rural road and *one non-critical* scenario on the motorway.

Effect of ACC support on subjective measures

Task demand : Effect of ACC support were found for motorway sessions but not for rural road sessions. Physical demands and effort were rated lower in supported driving. ***User acceptance*** : Drivers generally judged ACC quite favourably with respect to usefulness and pleasantness. ***Usability*** : was rated positively by participants.

"Preferred headway test"

Results revealed drivers' mean preferred minimum headway values comprised between 1.5 and 2.5 s on the motorway, and between 1.7 and 3.2 s on the rural road. These values were considerably longer than those practised in this experiment. These results might therefore be taken into consideration when discussing suitable minimum time headways in ACC systems.

Study	Törnros, J., Nilsson, L., Kircher, A. (2002). Effects of ACC on driver behaviour, workload and acceptance in relation to minimum time headway. In Proceedings of the 9th World Congress on Intelligent Transport Systems ITS. (**Supplementary study**)
Context	Moving base driving simulator; Motorway
2.1 Type of mediation	ACC, only one ACC minimum time headway of 1 s was used
2.2 Method	see above
2.3 Duration of test	Driving sessions were performed only on the motorway
2.4 Participants	8 participants (5 male, 3 female), age: 24-42 years (average 35); with a driving licence for 6-25 years (average 16)
2.5 Studied variables	Same as above + Workload : Performance detection task (PDT) and EEG
Summary	
A supplementary study was performed in order to gain further knowledge of effects of ACC on workload. To this end heart rate and PDT measures were used in addition to all other effects measures used in the main study. **Results** The PDT consisted in red less stimuli reflected in the windscreen of the simulator car. The led time period was randomly distributed between 3 and 5 s. They were lit for 2 s unless the driver responded by pushing a button. Reaction times were measured, and ECG was recorded. Calculations were performed for sections where no other traffic appeared. Heart rate decreased as an effect of ACC support for 3 scenarios. No effect was found for the PDT measures.	

Study	BjØrkly, C.A., Jenssen, G.D., Moen, T., Vaa, T. (2003). Adaptive Cruise Control (ACC) and Driver Performance: Effects on Objective and Subjective Measures. In Proceedings of the 10th World Congress on Intelligent Transport Systems, 16-20 nov 2003, Madrid, Spain
Context	Driving simulator An urban motorway setting of approximately 25 km, with a speed limit of 90 km/h
2.1 Type of mediation	ACC
2.2 Method	Measurement of behaviour indicators, scale (NASA-TLX), questionnaire and interview
2.3 Duration of test	Not reported
2.4 Participants	18
2.5 Studied variables	**Driving performance**: speed, time headway, use of brake and accelerator pedals; **Mental workload;** user acceptance and evaluation of suitable traffic environments for ACC use.

Summary

This study presented the Stardust ACC trials performed at the Sintef Driving Simulator. It included objective measures variables as speed, time headway and pedal use, both in baseline (without ACC), and in ACC conditions. The study included also subjective measures, as driver mental workload and user acceptance.

Results

Speed. The results indicated that ACC reduced top, variance and mean speed during drive.

Time Headway. They also indicated that drivers with ACC engaged had longer time headways than when driving without ACC.

Pedal use. more pressure was applied with ACC engaged. Post-interviews indicated that abrupt braking/disengagement of the ACC system was related to technology distrust.

Workload and acceptance. Subjective measures indicated a slightly higher mental workload with ACC, and a higher acceptance after trying the system in the simulator setting.

Study	Rudin-Brown, C.M., Parker H.A. (2004). Behavioural adaptation to adaptive cruise control (ACC): implications for preventive strategies. Transportation research Part F
Context	A 6.9 km closed test track
2.1 Type of mediation	ACC : two versions, one with short TH target (ACC-short, about 1.4 s) and long (ACC-Long, about 2.4 s)
2.2 Observation method	Instrumented car, scales (SSS and LOC) and questionnaires
2.3 Duration of test	1/2 H warm-up session + 3 “1/2 H driving sessions” (no ACC, ACC-short, ACC-long)
2.4 Participants	18 drivers (4 female and 12 male), driving regularly; age from 21 to 34; prior experience with conventional cruise control
2.5 Studied variables	**Driver characteristics**: Locus of Control (LOC) and Sensation Seeking (SS); **System characteristics**: ACC-Long and ACC-short; **Driver performance**: brake light reaction time, lane-keeping, lane departure, reaction time to the unexpected failure of the ACC in the ACC-long condition; **Secondary task**; **Subjective workload** (NASA-TLX), **trust in ACC**, sleepiness (Stanford sleepiness scale), **Drivers’ opinion** regarding ACC

Summary

The objective of this study was to investigate whether ACC has the ability to induce behavioural adaptation (BA) in drivers. Drivers were selected according two personal characteristics (LOC and SS). Two headway settings of an ACC system (short:, long: about 2.4 s) were tested. Throughout testing, drivers were instructed to perform a secondary task. They were also asked to perform a safety-relevant detection task (override the ACC system by pressing the brake pedal when noticing the lead vehicle’s brake lights illumination, noticing an unexpected failure of the ACC in the ACC-long condition).

Results :

Secondary task: ACC was associated with improved performance.

Safety-relevant brake light detection task. Participants reacted more slowly and responded within a **safe margin** 33 % less often, when using ACC. This effect was particularly pronounced in *high sensation seekers*.

Lateral position. ACC use was also associated with impaired lane-keeping performance, an effect that was also more evident in *high sensation seekers*.

Take-over situation. During a simulated failure of the ACC system, participants waited until the vehicle-to-vehicle headway was 0.6s before they intervened; *those with an external LOC took longer to react than those with an internal LOC*.

Trust in ACC. Finally, participants’ trust in ACC increased following exposure, and was not affected by the failure of the ACC system. Responses to interview questions revealed that all drivers relied on the ACC system to maintain speed and vehicle-to-vehicle headway.

Conclusion. ACC systems induce behavioural adaptation in drivers, in terms of changes in workload, hazard detection, and driving performance. The results suggest that, given the reduction in workload afforded by ACC, drivers using ACC may be tempted to allocate their attention to other driving tasks or to engage in other activities, while driving. It is possible, however, that any reduction in the efficacy of ACC due to BA could be minimised if effective driver training programs are implemented.

Annex 3: Summary of Revised studies - Mobile phone , Radio, CD, e-mail and navigation systems

Study	Nilsson, L., Alm, H. (1991) Effects of mobile telephone use on elderly drivers' behaviour – including comparisons to young drivers' behaviour. VTI särtryck Nr 176. VTI. Linköping. Sweden
Context	Driving simulator
2.1 Type of mediation	Mobile phone
2.2 Method	Driving performance, communication measures; subjective workload
2.3 Duration of test	80 km test route
2.4 Participants	10 men and 10 women, 60 – 71 years, experienced drivers, divided into two groups
2.5 Studied variables	Speed, lateral position, brake reaction time, subjective workload, communication measures
Summary	
The effect of a mobile phone conversation on elderly drivers' reaction time, lane position, variation in lane position, speed level and workload were studied in an advanced driving simulator. Twenty subjects, experienced drivers in the ages 60 – 71 years were randomly assigned to two conditions (mobile phone and control). It was found that the conversation over the mobile telephone had a negative effect on the elderly drivers' reaction time to a suddenly appearing event. Engagement in the mobile telephone task also led to speed reduction and increased variation in lateral postion. Finally, the drivers' mental workload, measured with NASA-TLX, increased when the telephone task was added to the driving task. The results were compared to the effects on twenty young drivers' behaviour, which was studied in an identical study. The comparison showed that the elderly drivers' reaction time to an unexpected event was approximately 0.40 seconds longer than the young drivers' reaction time, when talking in the mobile telephone while driving. The elderly drivers also varied their lateral position more than the young drivers, who tended to move to the right of the road and keep a steady course when talking in the mobile telephone. In contrast the elderly drivers kept the same mean position on the road, but increased their variation around that mean.	

Study	Alm, H., Nilsson, L. (1994) Changes in driver behaviour as a function of handsfree mobile phones – A simulator study. VTI särtryck Nr 221. VTI. Linköping. Sweden. (Also reported in: Alm, H., Nilsson, L. (1994) Changes in driver behaviour as a function of handsfree mobile phones – A simulator study. *Accident Analysis and Prevention, Vol 26, No. 4, pp. 441-451)*
Context	Driving simulator
2.1 Type of mediation	Mobile phone
2.2 Method	Driving performance, communication measures; subjective workload
2.3 Duration of test	80 km test route
2.4 Participants	20 men and 20 women, 23-61 years, experienced drivers, divided into four groups
2.5 Studied variables	Speed, lateral position, brake reaction time, subjective workload, communication measures
Summary	
The effects of a mobile telephone conversation on drivers' reaction time, lane position, speed level and workload in two driving conditions (easy versus hard driving task) were studied in an advanced driving simulator. 40 subjects, experienced drivers in the ages 23 to 61 years were randomly assigned to four experimental conditions. It was found that a mobile telephone conversation had a negative effect on drivers' reaction time, when the driving task was easy. It led to a reduction of speed, when the driving task was easy. It had a negative effect on drivers' reaction time, when the driving task was easy. It led to a reduction of speed, when the driving task was easy. It had a negative effect on drivers' lane position,	

most pronounced when the tracking component of the driving task was hard. Finally, it led to an increase in workload for both the easy and hard driving task.

Study	Briem, V., Hedman, L.R. & Radeborg, K. (1998). Behavioural and cognitive effects of mobile telephone use during simulated driving. *Proceedings of the 10th Nordic Traffic Medicine Congress, Reykjavik, Iceland, 27-28 August, 1998.*
Context	Driving simulator.
2.1 Type of mediation	Hands-free mobile telephone.
2.3 Duration of test	Three 20 min. secondary task blocks, with (i) simple and (ii) difficult telephone conversation (specifically involving judgement and memory), and (iii) car radio use. Half the driving was on firm and half on slippery road. Driving behaviour was classified in 4 categories, with driving on (i) a clear road, and with (ii) obstacles, (iii) communication, and (iv) instrument manipulation.
2.4 Participants	20 subjects (mean age = 33 years).
Summary	
Driving performance was clearly deteriorated on a slippery road, especially during instrument manipulation (radio and telephone). Easy telephone conversation was associated with least performance decrement, while difficult conversation tended to affect driving adversely. Prolonged manipulation of the telephone produced a performance decrement, particularly under conditions that put heavy demands on the driver's attention and skill. Cognitive performance was also deteriorated for the difficult telephone conversation, as regards judging the content of simple sentences and recalling the first words of sentences. There is a complex trade-off between performance on concurrent tasks, driving and mobile telephone communication. This is shown in an interference between similar sub-tasks, both primary and secondary (steering, speed control, instrument manipulation), and in a mutual interference between the primary and secondary tasks (driving - cognitive performance). This resulted in progressive decrements in both the simulated driving and the quality of an on-going telephone conversation, both as the driving became more difficult (and attention demanding) and as the topic of the conversation became more difficult (and attention demanding).	

Study	Tejerina L., Edwin Parmer, Michael J. Goodman (1998). Driver workload assessment of route guidance system destination entry while driving: a test track study. *Proceedings of the 5th ITS World Congress, Seoul, Korea, October 12-16, 1998*
System characteristics	Navigation Systems The test vehicle was a 1993 Toyota Camry, equipped with Micro-DAS instrumentation (Barickman, 1998). Four commercially available route guidance systems, three of them involving visual-manual demands and the fourth involving voice input and output. All of them allow destination entry while the vehicle is in movement. The dash mounted Delco Telepath 100® consisted of a 3-line LCD display to present menu items, scrolled by means of a bezel-mounted rotary knob and selected by pressing an Enter key. The Alpine NVA-N751A® incorporated a free-mounted 5.6 inch active matrix colour display without bezel keys. It displayed an alphanumeric keyboard and entries were made by scrolling from key to key with a joystick mounted on a remote control unit; pressing down on the joystick registered a character or selection. The Zexel Navmate® consisted of a free-mounted 4 inch diagonal full colour LCD screen with a set of bezel control keys, including a central “left, right, up, down” key and an Enter key. Finally, the dash mounted Clarion Eclipse® Voice Activated Audio Navigation (VAAN) system used voice recognition and output exclusively; there was no visual display. Keywords would activate the VAAN for destination entry. The driver uttered “verify” to conclude an entry. The system would eventuate in a spoken list of best-guess candidate destinations for selection by the driver via YES or NO verbal responses.
Context	Test track study
2.1 Type of mediation	Navigation Systems
2.3 Duration of test	7.5 multilane test track with light traffic. The experimenter firstly familiarized the test participant with each navigation system. Each participant then completed 12 practice data entry tasks per system, entered while the vehicle was parked. The order of trials were counterbalanced across the four route guidance systems, destination entry category and target.
2.4 Participants	Sixteen (16) test participants were recruited from the Transportation Research Centre Inc. pool of entry-level test drivers in equal numbers of males and females in each of two age categories: Younger (35 years or younger) and Older (55 years or older). These drivers were hourly employees with valid driver’s licences and generally less than 2 years of driving experience. None of the test participants owned or had significant prior experience with route guidance systems prior to this study..
2.5 Studied variables	A two-between, three-within mixed factors experimental design was used for this study. The between-factors were Age category and Gender. The within factors were: Route Guidance System (Zexel, Clarion Eclipse VAAN, Alpine NVA-N751A, and Delco Telepath 100); Destination Category (Street address, Cross street, or Point of Interest), and Destination Targets (Target 1, Target 2, different for each destination type but the same targets across each route guidance system). In addition, two non-destination entry tasks were included for comparison:

<table>
<tr><td></td><td>dialling an unfamiliar 10-digit number on a cellular phone and manually tuning a radio to a specific frequency on the AM and FM bands.
The dependent measures of interest for this study were: Visual Allocation (mean glance duration, mean glance frequency, and total glance time to road ahead, in-vehicle device, and note card); Driver-Vehicle Performance (number of lane exceedences, lane exceedence duration); and Trial Time (i.e., destination entry task completion time). Driver preferences and impressions of safety were also collected, among other subjective assessments. Lane exceedences represent one measure of degraded vehicle control that may be associated with driver inattention or distraction.</td></tr>
<tr><td colspan="2">Summary</td></tr>
<tr><td colspan="2">A significant effect of Age on destination entry trial time was found, with older drivers averaging almost twice as long as younger drivers. Times for Point Of Interest entry: the longest average completion time was with the Alpine system (118 seconds, approximately), the shortest average completion time was with the VAAN and Delco (approximately 75 and 78 seconds, respectively). Note also that all of the POI destination entry tasks took significantly longer than manually dialling an unfamiliar 10-digit number (approximately 28 seconds) or manually tuning a modern radio (approximately 22 seconds).
Age difference is “neutralized” by the use of the VAAN voice data entry system.
Older test participants made significantly greater numbers of glances per POI destination entry than younger participants (approximately 31 vs. 16 glances, respectively). The average number of glances per transaction were trivial for the VAAN in comparison with other route guidance systems, and even lower than the cellular telephone dialling and radio tuning tasks. The average mean single glance durations to the device for the VAAN is around 1.0 seconds, as compared with between about 2.5 seconds and 3.2 seconds for the other systems and comparison tasks.
Age had a significant effect on lane exceedences. The VAAN was associated with no lane exceedences.
Mean Eyes-off-Road-Time (EORT): older test participants spent about twice as long as younger test participants looking away from the road scene ahead. The VAAN was associated with the least amount of EORT. Test participant subjective assessments favoured voice input over visual-manual methods.</td></tr>
</table>

Study	Reed, M.P., and Green, P.A. (1999). Comparison of driving performance on-road and in a low cost simulator using a concurrent telephone dialling task. *Ergonomics, 42, 1015-1037.*
Context	Both driving simulator with two visual-scene fidelity and on road instrumented car.
2.1 Type of mediation	Manual dialling simulated phone system.
2.2 Method	
2.3 Duration of test	On-road testing: about 1 mile of surface streets and 22.4 km section of M-14, a limited-access highway. On the road the simulator: a simulated two-lane road was developed to match the geometry of the highway route. Four simulator runs were conducted of about 5 min each.
2.4 Participants	Twelve subjects. Six subjects were more that 60 years of age and six were between 20 and 30 years of age. Six were men and six were women. All subjects were currently licensed drivers and had corrected vision of at least 20/25. One younger male subject had used a car phone more than 20 times prior to the study. The other subjects had used a car phone than ten times. Subjects were paid $10/h.
2.5 Studied variables	On road driving performance, lane keeping, speed control.
Summary	
The simulated car-phone dialling task reduced driving precision both on the road and in the simulator. The decrement was lager for subjects over 60 years of age. Both on the road and in the simulator, measures of lane-keeping performance showed highly significant effects of the phone task. In the simulator, however, these effects were of considerably larger magnitude. The phone task increased the mean lateral speed in the car by 43%, while in the simulator the mean lateral speed increased by 158%. There was not effect on the speed control variable.	

Study	Lee, J.D., Caven, B. Haake, S. & Brown, T.L. (2000). Speech-based Interaction with In-vehicle Computers: The Effect of Speech-based E-mail on Drivers' Attention to the Roadway. *Cognitive Systems Laboratory (University of Iowa, Department of Industrial Engineering). Human Factors, 43, 631-640.*
Context	Medium fidelity driving simulator
System characteristics	Speech based interface for a prototypical in-vehicle computer application, an e-mail system
2.2 Method	Dirver performance, Scale and questionnaire
2.3 Duration of test	Drivers drove a series of 5-7 minute scenarios (one practice scenario and four experimental scenarios), in which they interacted with the e-mail system and responded to the erratic braking of a lead vehicle.
2.4 Participants	The participants included 24 drivers who had normal or corrected to normal vision. All had a valid driver's license, were undergraduate students of the University of Iowa, had never driven a driving simulator and ranged in age from 18 to 24. They were paid $6.50 an hour for the time they took to complete the experiment.
2.5 Studied variables	Measures of reaction time to the braking of the lead vehicle, of the subjective mental workload, of drivers' situation awareness were collected and perceived distraction.
Summary	
These results of this experiment support two important conclusions. First, speech-based interaction with in-vehicle information systems places a cognitive load on drivers that can affect driving performances. Speech-based interaction draws upon some of the same cognitive resources as driving and so can distract drivers just as visual displays and manual controls can. In driving conditions that require an immediate response, this distraction can undermine driving safety. Second, in this experiment, drivers generally recognized that speech-based interaction imposes a cognitive load and that increasing the complexity of the interaction imposes a greater load and is perceived as more distracting. An accurate perception of the distraction caused by an in-vehicle computer is a minimum requirement for modulating attention to the roadway. If the degree of distraction is underestimated then drivers may fail to shed the in-vehicle tasks when the driving tasks require full attention. Future research should examine how well this perceived distraction corresponds to the actual level of distraction. These results suggest speech-based interfaces should not be used indiscriminately and that careful attention to their design and the complexity of the underlying system is critical	

Study	Olsson, S. & Burns, P. C. (2000). Measuring Driver Visual Distraction with a Peripheral Detection Task. Department of Education & Psychology, *Linkoping University, Sweden; Volvo Technological Development Corporation, Gothenburg, Sweden.*
System characteristics	Radio, CD
Context	Real road driving (the test vehicle was a Volvo S80). The road trial started with a familiarization / practice drive. The next part was on a motorway and the last part was on a 2-lane undivided road with a number of traffic lights.
2.2 Method	The PDT presents a small red target light on the windscreen in the driver's perifoveal field of view. The target is a LED reflection on the windscreen (a heads-up display - HUD). Drivers respond to the targets by pressing a small button attached to their left index finger.
2.3 Duration of test	Not reported.
2.4 Participants	There were 13 participants in this study, six men and seven women aged between 24-44 years. They had held a valid driver license for between 4 and 26 years. Six participants wore glasses or lenses while driving. Data from two participants (men) could not be used since their response data was corrupted. This left 11 participants with complete data for the analysis.
2.5 Studied variables	The Peripheral Detection Task (PDT) is a method for measuring the amount of driver mental workload and visual distraction in road vehicles. It is a secondary task measure where drivers must respond to random targets presented in their peripheral view. The independent variables were road type/speed, motorway (110 km/h) and country road (90 km/h) and task, embedded or cognitive. The embedded tasks were to determine the tuned frequency on the radio and manually select a specific radio station (Task 1, Radio), and turn on the CD-player and play a specific track on a specific CD, for example, track 3 on CD 1 (Task 3, CD). The cognitive task used was a backward counting task, for example 568-7 (Task 2, Counting). The dependent measures were heart rate variability, subjective mental effort, PDT reaction time and target hit rate.
Summary	
The results indicated that the peripheral detection task (PDT) is a sensitive measure of the distraction from in-vehicle tasks while driving on real roads and using a small sample of subjects. The PDT reaction time and hit rate measures revealed significant differences between the different tasks. Mean reaction times were slowest for the backward counting task on the country road. The hit rates were best for the baseline driving on both roads and worst for the CD task. No significant difference was found between the motorway and the country road for the PDT. If more PDT targets are missed because the driver is distracted, it may be assumed that under similar circumstances more road signs, pedestrians or other relevant objects may also be missed.	

<table>
<tr><td>Study</td><td>Parkes, A. & Hooijmeijer, V. (2000). The influence of the use of mobile phones on driver situation awareness. Transportation Research Lab., Crowthorne, England, 2000.</td></tr>
<tr><td>Context</td><td>A static driving simulator (the route used in the simulation was a single carriageway in a countryside environment, with smooth horizontal and vertical curves equally spread along the track length, and with a high level of oncoming traffic).</td></tr>
<tr><td>System studied</td><td>Hands free mobile phone</td></tr>
<tr><td>2.2 Method</td><td>Behaviour measurements, questionnaires</td></tr>
<tr><td>2.3 Duration of test</td><td>Participants drove a total length of 15.5 miles, while they were asked a series of questions via the hands-free car phone.</td></tr>
<tr><td>2.4 Participants</td><td>15 volunteer subjects, all students at a UK university, aged from 22 to 31, with more than 3 years of driving experience, and little or no experience with using a mobile phone while driving.</td></tr>
<tr><td>2.5 Studied variables</td><td>Reaction time to unexpected events, braking profile, lateral position, speed and situation awareness.
All three levels of situation awareness were measured by questions directed to the subject at two fixed locations after the start of the test (stopping the simulation).</td></tr>
<tr><td colspan="2" align="center">Summary</td></tr>
<tr><td colspan="2">The mean reaction time to the various stimuli in the phone and no-phone situation was found non-significant. The reaction time to the first choice reaction event was longer than the others, probably due to the fact that this first event appeared rather soon after the start of the conversation. This would imply that drivers are slower in their reactions when a phone conversation just has started, but the effect reduces over time.
No significance found in the mean lateral position and the variability in lateral position.
There is no observable difference between the mean reaction to the change in speed limit from 50 to 80 km/h in the phone and no-phone situation. The change from 80 to 50 km/h however seems to be slower in the phone situation.
There were significantly more correct answers to the situation awareness questions in the no-phone situation at both locations.
A main limitation of this study is that the measurements took place in a safe, simulated environment. In addition to this, the simulated road was a countryside environment, with a reasonable amount of surrounding traffic, but no direct conflicts with other cars. The road driven did not have sharp curves or large junctions. As a result, the driving task was rather easy. The phone task on the other hand consisted of a selection of verbal and numerical questions and was rather difficult to perform.
The results have shown that a young well-educated group of drivers were able to engage in a difficult car phone conversation and cope with basic control elements of driving reasonably well. However even this group showed a dramatic fall off in situation awareness due to the level of concentration demanded by the car phone conversation.</td></tr>
</table>

Study	Haigney, D.E., Taylor, R.G., and Westerman, S.J. (2000). Concurrent mobile (cellular) phone use and driving performance: task demand characteristics and compensatory processes. *Transportation Research* Part F, 3, 113-121.
System studied	Hands-free and hand-held phones.
Context	Driving simulator.
2.2 Method	Behaviour measurements, questionnaires
2.3 Duration of test	Four simulated drives. Each simulated drive comprised three 150s periods: (i) 'pre-call; (ii) 'during call', and (iii) 'post-call'.
2.4 Participants	Thirty participants (13 male, 17 female) were recruited for this study (mean age=26.93 years, S.D.=3.06). Each had held a UK manual transmission driving license for private and light goods vehicles (PLG) for at least one year (M 4.37 years, S.D. 1.73). UK, drivers holding a full PLG manual transmission license are qualified to drive PLG automatic transmission and so this was deemed an adequate gauge of basic driving skill for this experimental design (Zeier, 1979). Sixty three percent of the sample had previous experience of using a mobile phone; 13% of the sample had experience of using a hands-free phone; and 20% of the sample used a mobile phone while driving with a frequency of once per week or greater.
2.5 Studied variables	Heart rate, Mean speed, standard deviation of accelerator pedal travel, brake pedal travel, and number of gear changes were logged every 0.5 s. In addition, number of overtakes, number of off-road excursions (OFFS), and number of collisions were recorded as dependent measures.
Summary	
Using a mobile phone while driving imposes additional load relative to driving without concurrent phone use, mean heart rate was higher in the during call period of this experiment than either the pre-call or post-call periods. The fact that there was no interaction with phone type (hand-held vs hands-free) indicates that this increase was not related to the physical demands associated with holding the phone. Instead, it would seem that participants were finding task performance cognitively more effortful in the during call period, and were having to invest greater attentional resources in task performance. The results of this study also supported the hypothesis that drivers engage in compensatory behaviour and attempt to reduce workload when using a mobile phone to enable perceived required safety margins to be achieved.	

Study	Salvucci, D.D. (2001). Predicting the effects of in-car interface use on driver performance: An integrated model approach. *International Journal of Human-Computer Studies, 55, 85-107.*
System studied	Four dialling interfaces: (1) Full-manual; (2) speed manual; (3) Full-voice; and (4) speed-voiced
Context	One-lane roadway in a fixed-based driving simulator.
2.2 Method	
2.3 Duration of test	After some practice, drivers drove the one-lane road at a speed of approximately 60 mph and were asked to dial the phone at 20s intervals.
2.4 Participants	Eleven drivers (five women and six men) participated in the experiment ranged in age from 19 to 32 with and average age of 25. Of these 11 drivers, three use a cell phone regularly, and all three have used a cell phone while driving. Of the eight who do not use a cell phone regularly, four have used a cell phone at some point while driving.
2.5 Studied variables	Lateral deviation, dialling time.
Summary	
(1) the full-manual interface had large significant effects on driver performance, the speed-manual interface had small significant effects, and the voice interfaces had no significant effects; (2) The speed-manual interfaces required the least time, followed by speed-voiced interface, the full-manual interface, and finally the full-voice interface.	

Study	McCarley, J. S., Vais, M., Pringle, H., Kramer, A. F., Irwin, D. E., & Strayer, D. L. (2001). Conversation disrupts visual scanning of traffic scenes. *Paper presented at Vision in Vehicles, Australia.*
System characteristics	Hands-free cellular phone.
Context	Driving simulated task. Observers were asked to search for changes within complex traffic scenes, either while concurrently maintaining a conversation or under single-task control conditions. Visual stimuli (urban and suburban traffic scenes as viewed from a driver's perspective) were presented on a 121.92 cm x 167.64 cm display (ImmersaDesk).
2.3 Duration of test	Each trial, the observer viewed a repeating cycle of four displays: an unaltered image (240 ms), a grey screen (80 ms), the modified version of the first image (240 ms), and another grey screen (80 ms). The observer's task was to detect and report the difference between the unaltered and altered images. Upon detecting a change, the observer made a button press on a joystick to terminate the stimulus, then described the detected change to the experimenter. Each observer completed 40 single-task trials, involving only the change detection task, and 40 dual-task trials, which required the observer to perform the change detection task while conversing with a confederate.
2.4 Participants	Fourteen younger observers, mean age = 21.43 years, and fourteen older observers, mean age = 68.43 years, participated. All participants were native English speakers, had corrected visual acuity of 20/40 or better, and had held a driver's license for at least one year prior to the date of testing.
2.5 Studied variables	Reaction time (RT) for the button press was recorded, and accuracy of the described change was noted.
Summary	
Results demonstrate that even simple conversation can disrupt attentive scanning and representation of a visual scene. Error rates for change detection were higher during conversation than under single-task conditions, and larger numbers of saccades were necessary to locate and respond to the changing item. Critically, observers' conversations in the current experiment were "hands-free"; dual-task conditions did not require observers to hold or manipulate any apparatus beyond the joystick and response button which were also used under single-task conditions, nor to visually inspect any additional stimuli. Thus, the interference imposed by conversation was apparently not structural, but cognitive. Dual-task interference may be especially harmful for older observers' performance in real-world circumstances.	

Study	Nunes, L., and Recarte, M.A. (2002). Cognitive demands of hands-free-phone conversation while driving. *Transportation Research Part F, 5, 133-144*
System studied	Hands-free phone, no details.
Context	Spanish highway with real traffic and normal daylight conditions. Argos instrumented car.
2.3 Duration of test	No details
2.4 Participants	Six drivers of both sexes. No more details about them.
2.5 Studied variables	Visual detection, discrimination and response selection capacities while performing phone tasks. Basic ocular parameters such as fixations coordinates, fixation duration and pupil size. Subjective measures of cognitive efforts.
Summary	
Low demanding phone conversations produced null or low effects and high demanding phone conversations affected significantly the visual processing capacities. Talking on a hands-free phone is like talking with a passenger but the conversation content and its complexity are really potential distractors.	

Study	Strayer, D. L., Drews, F. A. & Johnston, W. A. (2002). Why do cell phone conversations interfere with driving? *Proceedings of the 81st Annual Meeting of the Transportation Research Board, Washington, DC.*
System studied	Hands-free and hand-held mobile phone. Also, a radio and a book-on-tape were used.
Context	Experiment 1: a simulated driving task. Subjects performed a pursuit tracking task in which they used a joystick to manoeuvre the cursor on a computer display to keep it aligned as closely as possible to a moving target.
2.3 Duration of test	An experimental session consisted of three phases: the first phase was a warm-up interval (7 min), the second phase was the single-task portion of the study (7.5 min before and 7.5 after the dual task) and the dual-task portion of the study (15 min).
2.4 Participants	Sixty-four undergraduates (32 male, 32 female) from the University of Utah participated in the experiment. Subjects ranged in age from 18 to 30. All had normal or corrected-to-normal vision and perfect colour vision. Subjects were randomly assigned to one of the radio control, book-on-tape control, hand-held cell phone, or hands-free cell phone groups.
2.5 Studied variables	Braking reaction times to a red light.
Summary	
These data demonstrate that the phone conversation itself resulted in significant slowing in the response to simulated traffic signals, as well as an increase in the likelihood of missing these signals. Moreover, the fact that hand-held and hands-free cell phones resulted in equivalent dual-task deficits indicates that the interference was not due to peripheral factors such as holding the phone while conversing. These findings also rule out interpretations that attribute the deficits associated with a cell phone conversation to simply attending to verbal material, because dual-task deficits were not observed in the book-on-tape control. Active engagement in the cell phone conversation appears to be necessary to produce the observed dual-task interference.	

Study	Strayer, D. L., Drews, F. A. & Johnston, W. A. (2002). Why do cell phone conversations interfere with driving? *Proceedings of the 81st Annual Meeting of the Transportation Research Board, Washington, DC.*
System studied	Hands-free mobile phone.
Context	Experiment 2: a high-fidelity driving simulator (The PatrolSim high-fidelity driving simulator by GE Capital I-SIM). Subjects drove on a multi-lane freeway in single-task (i.e., driving only) and dual-task (i.e., driving and conversing on a cell phone) conditions. In both conditions, subjects followed a pace car that would, on occasion, brake in response to unexpected events.
2.3 Duration of test	When subjects arrived for the experiment, they completed a questionnaire (about their driving behaviour and also their interest in potential topics of cell phone conversation). Subjects were then familiarized with the driving simulator (15 minute adaptation sequence). Subjects then drove four ten-mile sections on a multilane highway. Half of the scenarios were used in single-task driving conditions and half were used in dual-task (i.e., driving and cell phone conversation) conditions.
2.4 Participants	Forty undergraduates (18 male and 22 female) from the University of Utah participated in the experiment. Subjects ranged in age from 18 to 32. All had normal or corrected-to-normal vision and perfect colour vision.
2.5 Studied variables	Measures of real-time driving performance, including driving speed, distance from other vehicles, brake, gas, and steering wheel inputs, were sampled at 30 Hz.
Summary	
Results from both Experiment 1 and Experiment 2: The principal findings are that subjects engaged in cell phone conversations were more likely to be involved in traffic accidents, missed more traffic signals, and reacted more slowly to events in the driving environment than when they were not engaged in cell phone conversations. Equivalent deficits in driving performance were obtained for hand-held and hands-free cell phone users. Indeed, performance decrements were obtained in Experiment 2 even when there was no possible contribution from the manual manipulation of the cell phone. An analysis of the driving profiles revealed that the reactions of cell phone users were sluggish and that subjects attempted to compensate for this sluggish behaviour by increasing the distance from the vehicle they were following. However, the observed incidence of traffic accidents suggests that this compensatory strategy was inadequate. Moreover, as driving difficulty increased, the costs of cell phone use were exacerbated. These data are consistent with an attention-based interpretation in which the disruptive effects of cell phone conversations on driving are due primarily to the diversion of attention from driving to the phone conversation itself.	

Study	Piechulla, W., Mayser, C., Gehrke, H, König, W. (2003). Reducing drivers mental workload by means of an adaptive man–machine interface. *Transportation research Part F*, *6*, 233-248.
System studied	Mobile phone connected to an adaptive man–machine interface that filters information presentation according to situational requirements.
Context	Driving simulator.
2.2 Method	Behaviour measurements, questionnaires
2.3 Duration of test	Participants drove through an experimental route of 27 km three times.
2.4 Participants	Participants consisted of 6 younger male drivers who were from 21 to 29 years old (M: 24.28 years, SD: 3.60 years), and 6 male novice drivers (M: 18.26 years, SD: 0.33 years). The experienced drivers were holding a driving license for at least some years (M: 6.80 years, SD: 3.29 years), novices had gotten their driving licence 50 days before the experiment on average (M: 0.14 years, SD: 0.08 years). Experienced drivers were recruited from the student population of Universität Regensburg, novices from a local driving school.
2.5 Studied variables	Heart rate, EMG, ECG, NASA-TLX.
Summary	
The results of system evaluation show a reduction of mental workload in the adaptive telephone condition, where incoming telephone calls are not signalled to the driver, but redirected to the mailbox whenever the workload estimation exceeds threshold. Video ratings show that while the workload for experienced drivers is reduced significantly, this is not the case for beginners.	

Study		Vägverket (2003) Vetenskaplig rapportsamling – Vägverkets utredning om användning av mobiltelefoner och andra IT-system under körning. Vägverket publikation 2003:92. Vägverket. Borlänge. Sweden.
Context		Moving base simulator
2.1 Type of mediation		Mobile phone (hands free (HF) and hand held (HH))
2.2 Method		Driving performance; secondary task
2.3 Duration of test		A 70 km route with a driving time of approx 1 hour 10 minutes
2.4 Participants	HF	12 male, 12 female
	HH	14 male, 10 female
2.5 Studied variables		Speed, Lateral position, Steering wheel angle, Longitudinal acceleration, Side acceleration, distance to vehicle in front, reaction time, PDT
Summary		
These studies were part of a larger study where the effects of mobile phone conversation (HH and HF), text messaging and watching a DVD film were investigated. The main result of the study was that mental workload as measured by PDT (Peripheral Detection Task) – reaction time and missed signals – increased by mobile phone conversation for both HH and HF in all traffic environments and all events. The effects were very similar for the two phone modes. Lateral control of the vehicle was also affected by the two phone modes. The variance in lateral position decreased and the maximum lateral acceleration decreased for the hands free mode and there were similar tendencies for the hand held as well. The effects might be interpreted as attempts to compensate for the increased workload but it can also be that it is an effect of increased driver alertness, reduced speed or the fact that steering has become less prioritised. Speed was reduced when the driver was using the phone, both for HH and HF. It was especially in two situations that speeds were affected, a rural environment with the highest speed limit in the study (90 km/h) and an urban environment with the highest complexity. With the HH speeds were also reduced in two other environments. Although the difference in speed was not significant for the two phone modes for any of the studied situations separately, the speed reduction across all studied situations was greater for the HH. It is assumed that this is an attempt to compensate for the increased workload. Longitudinal interaction was also affected by the phone conversation. The brake reaction time increased at one event for the HH but no effect could be found for any other situations, maybe as a result of the reduced speeds in these situations. Minimum time headway and minimum distance headway increased for both phone modes, possibly an attempt to compensate. The mental workload increased as a result of the phone use, in spite of the drivers' attempts to compensate by reducing speeds and increasing headways. It can be assumed that the increased mental workload caused by the phone conversation would have negative effects from a traffic safety perspective in terms of drivers' readiness to react in a risky situation. To what extent the drivers' compensation for this is sufficient or not is still unclear. Questionnaire answers did not reveal any difference in perceived effort between the two phone modes, which is in line with the PDT-measurements. The opinion among the participants was however more positive towards the HF. In addition they rated their performance higher for the HF than the HH.		

Study	Harms, L., and Pattern, C. (2003). Peripheral detection as a measure of driver distraction. A study of memory-based versus system-based navigation in a built-up area. *Transportation research Part F, 6*, 23-36.
System characteristics	An instrumented car (Volvo, Model 850S, 2.5, 1996 with manual gearbox) equipped with an IVIS for navigation (VDO Dayton, MS 5000).
Context	Real driving situation In a built-up area of the city.
2.3 Duration of test	Not reported.
2.4 Participants	Twenty-four male, professional drivers participated in the experiment. Eighteen subjects were taxi-drivers in the local area (Linköping) and the other six were professional drivers in the same area. All subjects were highly skilled drivers, familiar with having IT components in their vehicles and familiar with driving in the built-up area in which they were required to drive. Their reported total annual mileage was 10,000–120,000 km with a mean of 60,000 km. The subjects were aged 30–60 years, fourteen subjects were between 40 and 50, six were younger than 40 and four were older than 50.
2.5 Studied variables	PDT-performance, driving speed, brake activity, steering wheel angle, lateral position and distance headway were registered automatically with a frequency of 5 Hz. PDT is a peripheral detection task used to measure mental workload.
Summary	
Only PDT-performance was affected by navigation condition (i.e. driving with or without navigation system). Driving speed and the other aspects of driving behaviour observed in the study (i.e. brake frequency and brake force), were virtually unaffected by navigation conditions and message modality).	

Study	Sullman, M.J.M, & Baas, P.H (2004). Mobile phone use amongst New Zealand drivers. *Transportation Research Part F*, *7*, 95-105.
System studied	Hands-free and hand-held mobile phone.
Context	Out of driving
2.1 Type of mediation	
2.2 Method	Questionnaires, distributed, along with reply paid envelopes, at petrol stations in four urban areas in the North Island of New Zealand.
2.3 Duration of test	It is a correlational study with data collected by using a questionnaire.
2.4 Participants	Participants were drivers who had driven at least once in the last six months. In total, just over 1700 questionnaires were distributed and 861 responses were received, giving a response rate of just over 50%.
2.5 Studied variables	Frequency of mobile phone use, crash involvement, demographics and descriptive variables.
Summary	
Although this research found a significant correlation between the frequency of cell phone use and crash involvement, once the contributions of the demographic and descriptive variables had been partialled out the relationship between the two was no longer significant. This result is in contrast to previous research which has found using a mobile phone whilst driving significantly increases the risk of being crash involved (Redelmeier & Tibshirani, 1997; Violanti, 1998; Violanti& Marshall, 1996).	

Study	Thulin, H., Gustafsson, S. (2004) Mobile phone use while driving – Conclusions from four investigations. VTI report 490A. VTI. Linköping. Sweden
2.1 Type of mediation	Mobile phone
2.2 Method	Questionnaires & Focus groups
2.3 Duration of test	-
2.4 Participants	Varying from 24,926 respondents 14
Summary	
Most of the facts in this reports is on usage (where, when, how much) and type of equipment. Some behavioural effects were however found, especially in the focus groups but also in the questionnaires. In the focus groups drivers stated that there was less concentrating and the drive became unsteady. It was also found that the use of mobile phones resulted in getting lost, missing exits and missing change of lights at intersections. From the questionnaires it was reported that almost half of the drivers had been so concentrated on their mobile conversation that they had missed an exit or traffic signal, swerved into the wrong or opposing lane, lost control of the car so it started to slide, or kept too high or too low speed relative traffic conditions. This was especially evident for the younger drivers. "Keeping to low speed in relation to traffic conditions" was the most usual response followed by "Missed an exit or an onramp". The older participants said they generally reduced their speed while driving and using a mobile phone while the younger drivers did not.	

Study	Patten, C., Kircher, A., Östlund, J., Nilsson, L. (2004) Using mobile telephones: cognitive workload and attention resource allocation. *Accident Analysis and Prevention. Vol 36, Issue 3, pp 341-350*
Context	real driving situation
2.1 Type of mediation	Mobile phone
2.2 Method	Instrumented vehicle on motorway driving, simple and complex conversation
2.3 Duration of test	74 km test route
2.4 Participants	40 professional drivers, 21 – 60 years, 32 men and 8 women
2.5 Studied variables	PDT-data (reaction time and hit rate), speed
Summary	
Driver distraction is recognized as being one of the central causes of road traffic incidents and mobile telephones are tangible devices (among many other electronic devices) that can distract the driver through changes in workload. Forty participants completed a motorway route characterized by a low level of road complexity in the form of vehicle handling and information processing. A peripheral detection task (PDT) was employed to gauge mental workload. We compared effects of conversation type (simple versus complex) and telephone mode (hands-free versus handheld) to baseline conditions. The participants' reaction times increased significantly when conversing but no benefit of hands-free units over handheld units on rural roads/motorways were found. Thus, in regard to mobile telephones, the content of the conversation was far more important for driving and driver distraction than the type of telephone when driving on a motorway or similar type of road. The more difficult and complex the conversation, the greater the possible negative effect on driver distraction.	