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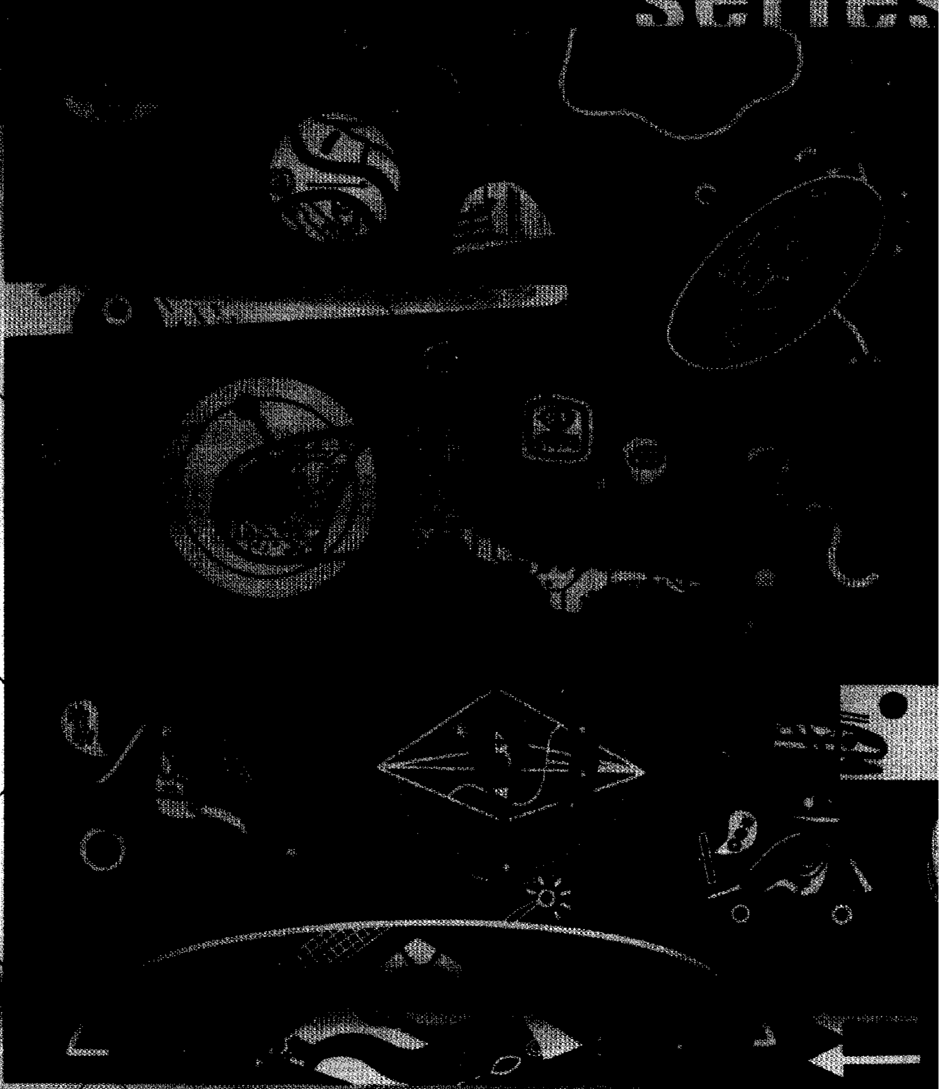

Driving with intelligent [illegible]

Driving with intelligent vehicles

Driving behaviour with Adaptive Cruise Control and the acceptance by individual drivers

Marika Hoedemaeker

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Driving with intelligent vehicles

Driving behaviour with Adaptive Cruise Control and the acceptance by individual drivers

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1. Introduction

This first chapter outlines the research questions of this thesis and the framework in which these research questions will be answered.
The background and problem area are presented and an illustration is given of what is meant by the term 'driver support systems'. In addition, the objectives of and the research methods used in this thesis are discussed and the contents of subsequent chapters are introduced.

1.1 Background

During past decades Western society has been increasingly confronted by problems in traffic and transport. Road transport is growing too fast and this has negative repercussions on energy, emissions, traffic safety and road capacity (congestion). In future decades the mobility of people and goods will only increase (and so the pressure on existing transport systems and the environment will increase. An obvious solution would be to increase infrastructure (build more roads), but in the long run this would not be sufficient to meet the growing needs. Another solution would be to influence the choice of transport mode and to change it from cars to other transport modes like trains, buses etcetera. In recent government mobility plans, measures are mentioned that aim to reduce individual car usage, like "rekening rijden", introducing electronic pay lanes and dedicating lanes to specific road users. It is generally recognised that an important contribution to the solution for the problems in traffic and transport might be to apply new technologies that are supported by telematics.

One of these new technologies is the category of driver support systems, which is regarded as a promising tool for improving road network traffic performance and safety. Driver support systems are defined as systems in which the driving task of a driver is partly or entirely taken over by an automated system. Such automation of driver tasks might improve traffic safety and driver comfort, increase road capacity or limit energy consumption and emissions. Most experts assume that the development of driver support systems will be evolutionary, characterised by a gradual increase of automation of vehicle driving tasks in time (e.g. Hall, 1997; Stevens, 1997; see also chapter 2).

The research focus in this field is switching from technological development and improvement to technological implementation. Technological feasibility is not the main issue anymore. Instead, several authors specifically emphasise the need to identify general possibilities and constraints if driver support systems are to be introduced on a large scale, and to find ways of coping with such uncertainties (e.g. Banister, 1994; Hall & Tsao, 1994). These needs have become the central challenge of the research programme "Technology Assessment Automatic Vehicle Guidance", initiated in 1994 by the Dutch Research School on TRAnsport, Infrastructure and Logistics (TRAIL). This programme includes four, interdependent, PhD projects, on introducing driver support systems to road traffic, each of which concentrates on one of four aspects:

- Policy making and societal consequences:
  This project focuses on plausible future technological developments as well as the identification of necessary societal and political conditions for these developments.

- Road capacity and traffic flow:

  This project models traffic flows assuming various scenarios for driver support implementation. Furthermore, attention is paid to the requirements for infrastructure design that result from these scenarios.
- Legislation and liability aspects:

  This project deals with the legal aspects of driver support implementation. What are the consequences for safety and liability? Can we simply refer to product liability laws and standards?
- Individual driver behaviour and acceptance:

  It is this last aspect of effects of driver support systems on individual driver behaviour and drivers' acceptance of these systems that is the subject of this thesis.

The impact of driver support systems on individual drivers can be gauged on a continuum going from purely informative to completely interventionist. Purely informational systems, for example RDS-TMC (Radio Data System - Traffic Message Channel) on a car radio, can easily be ignored, while some of the more interventionist systems may go as far as actually taking over control of the vehicle and thus reducing the driver's input to nil. In between these extremes, several driver support and feedback systems were and are being developed.

While these systems might work well in terms of technical performance, the effects on driver behaviour are not a priori positive. Most systems aim to support the driver, but the increase in the quantity of in-vehicle equipment increases the demands on the driver's information processing system by adding on-board displayed information (see e.g. Dewar, 1988). Apart from this, the new equipment might lead to behavioural adaptations, which could be dangerous. Drivers could take more risks as they rely on a system support (Hayashi et al., 1997). Furthermore, as equipped vehicles will become safer and more comfortable, car usage would become more attractive, possibly causing increased car use (Banister, 1994). Excessive reliance on driver support systems might result in serious accidents in cases of system failure. Other systems that actually take over control might turn driving into a vigilance task (Kantowitz, 1992). Finally, it is not only safety effects that determine successful introduction and operation; sometimes what is even more important is the issue of social acceptance (Rothengatter et al., 1991).

1.2 Research questions

The extent to which driver support systems realise their goals of increasing traffic safety and efficiency will depend, among other things, on how they affect driving behaviour and how many people are willing to drive with such systems. Besides, drivers have very different preferences and styles of driving. In 1990 the OECD already stated that "drivers employ the vehicle technology available to them in order to suit their driving purpose, motivation and driving style". Individual driver needs and driving styles are therefore the starting point in this research. It is expected that whenever driver support systems frustrate these needs and driving styles, acceptance of the systems is low and unwanted or even dangerous reactions of drivers may occur.

The main research questions are:

1. What are the effects of driver support systems on driving behaviour?
2. To what extent will driver support systems be accepted by individual drivers?
3. To what extent will driving behaviour and acceptance be determined by individual differences?

1.3 Objectives and methods

In order to answer these questions two types of research were carried out: a large questionnaire study and two experimental studies in a driving simulator.

The questionnaire study consisted of a survey that was sent to 1000 car-driving members of the Dutch Automobile Association (ANWB), aimed at studying their (1) judgements towards driver support systems (2) their needs or motivations when driving and (3) their preferred driving styles. This last part was based on the Driving Style Questionnaire (DSQ), developed by West et al. (1992). The other two parts were developed in this project.

The experimental studies were aimed at studying the effects of different forms of driver support systems on driving behaviour and acceptance. In the driving simulator at the Centre for Environmental and Traffic Psychology (van Wolffelaar & van Winsum, 1992), participants could actually drive with these systems, which enabled driving behaviour on-line and acceptance after participants had experienced driving with these systems to be measured. The driving simulator has a fixed base and consists of a normal car (a BMW 518) with normal operation (steering wheel, clutch, gears etcetera). A computer calculates the images of the outside world, projected on a semi-circular screen, based on the actions of the driver in the BMW. Other cars "drive" independently through the simulated world, according to their own behaviour rules, interacting with each other and with the BMW. One advantage of simulators, which is important in behavioural research, is that they allow driving conditions and environmental conditions to be kept under control, so all subjects can be exposed to exactly the same conditions. Moreover, it is possible to test and evaluate proposed driver support systems during the conceptual phase of the development, which is the case in the current research.

1.4 Outline of the thesis

In chapter 2 the field of development with possible driver support systems is explored. The impacts on traffic safety and road capacity are considered and an option is made for the systems which are the focus of this thesis.

To be able to contemplate the implications of driver support systems for driving behaviour, it is necessary to assess the factors that play a part in driver behaviour. Consequently, chapter 3 includes a description of the existing driver behaviour models and outlines what are the most important implications of those models for the implementation of driver support systems. Also, a hierarchical framework of driver behaviour is presented in which cognitive constructs such as driver needs are connected to low level operational driving tasks. With the aid of this hierarchical driver model, predictions can be made about how automation of particular driving tasks may influence overall driving behaviour and to what degree these may be driver dependent. The subsequent research is based on these predictions.

Chapter 4 describes the different research methods and instruments that were used. In this chapter it is argued why these methods were chosen, based on their known advantages and disadvantages, and reliability and validation issues of the driving simulator are discussed.

In Chapter 5 the results of a questionnaire study about Dutch car drivers characteristics are presented. The research questions of this study are: What are the needs and driving styles of drivers and is there a relation between the two? The results of this study give more insight into the needs and driving styles of car drivers and into their judgements of four different driver support systems.

On the basis of the results of the questionnaire study, groups of drivers were formed who differed in their needs regarding driving, and also in their driving styles; particularly with respect to their speed and the degree to which they are easily distracted by irrelevant events (focus) while driving. It is hypothesised that these driver groups will show a differential reaction to driver support in terms of driving behaviour and acceptance. This is the starting point of the experimental study described in chapter 6. In this study the effects of different forms of an Adaptive Cruise Control (ACC) were tested in a motorway driving simulator environment with four groups of subjects who differed in their reported driving styles "speed" and "focus".

In chapter 7, a second driving simulator experiment is described in which hypotheses were tested with respect to ACC use on two types of roads: motorways and rural roads. Based on results of the previous driving simulator experiment, only drivers differing in their driving style regarding speed were participating, because it was shown that, in particular, these drivers have different reactions to driving with an ACC.

The last chapter summarises the conclusions of the studies that were carried out. After a discussion of the implications from the partner projects, the results are linked to the theoretical issues raised in chapter 3 for more general implications of this thesis. The chapter is concluded with implications for further research and general conclusions.

2. Driver support systems

Driver support systems are intelligent systems that support the driver in performing one or more elements of the driving task. This chapter outlines the systems that can be summarised under the term "driver support systems". It describes their expected effects in terms of traffic safety, road capacity and driver comfort. Also driver behaviour reactions and acceptance issues are discussed. Because the range of possible driver support systems is very wide, from systems that maintain a proper speed or distance to a vehicle in front to fully automated driving, this chapter describes only those systems that are generally recognised as the first steps towards fully automated driving and the end-station, the autopilot. Systems that only inform the driver, the so called information systems, are not described because they do not fall under the definition of driver support systems. The chapter concludes with a choice for a driver support system, which is the focus of the remainder of this thesis: adaptive cruise control.

2.1 Introduction

In future decades an increase in technological devices in vehicles is expected as a result of ongoing progress in electronics. Various systems that support the driver in controlling the vehicle are currently under attention. These systems are denoted by a variety of terms, such as Intelligent Transportation Systems (ITS), Automatic Vehicle Guidance (AVG), or Advanced Vehicle Control Systems (AVCS). In this study the term driver support systems is used, because it refers to its most important characteristic: the support of the driver with performing one or more parts of the driving task.

To summarise, driver support systems are intelligent systems that support the driver by *taking over partly or entirely his/her driving tasks.*

Information systems (like route guidance or traffic information systems) do not fall under this definition, because they only inform the driver and do not intervene with (one of) the driving tasks, although these systems can definitely support or influence the driving task.

The automation of driving tasks could potentially improve driver comfort, by facilitating the driver's tasks and decreasing the amount of necessary actions. It could also potentially improve traffic safety, by reducing the severity or incidence of certain types of collisions. And by establishing a harmonisation of traffic flow, it could also potentially increase road capacity or limit energy use (e.g. Glathe, 1998). However, there may be negative (side) effects. Drivers could adapt their driving behaviour by taking extra risks in response to the increase in traffic safety or to an increase in mobility because of increasing comfort and a better accessibility to more traffic participants.

Because the range of possible driver support systems is very wide; from systems that maintain a proper speed or distance to a vehicle in front to fully automated driving, this chapter describes those systems that are generally recognised as the first steps towards fully automated driving and the autopilot itself. These systems are:

- Speed and headway support (longitudinal control, see section 2.3)
  These systems detect the preceding vehicle and support a driver by maintaining a safe distance between the vehicles. In the case of a potential collision with a moving or stationary obstacle ahead they warn the driver and/or control the vehicle.
- Lane keeping support (lateral control, see section 2.4)
  These systems warn the driver and/or control the vehicle temporarily, in case of impending road departure.
- Autopilot (both longitudinal and lateral, see section 2.5)
  All driving tasks are fully automated by this system, allowing hands-off, feet-off driving.

2.2 Classification of driver support systems

The most important classification axis of driver support systems is the direction of the driver task that is supported or taken over by a system. *Longitudinal* support systems concern driving tasks in the forward direction of driving, such as speed and headway keeping. *Lateral* support systems concern driving tasks in the sideward direction like lane keeping, and *integrated* support concerns tasks in both forward and sideward directions.

The level of automation represents the second axis of driver support systems. *Overrulable assisting* driver support systems take over the driving task automatically, but the driver can always take over vehicle control while the system is activated. *Non-overrulable assisting* driver support systems aim to replace (parts of) the driving task completely without driver co-operation, most likely on dedicated lanes. The system decides whether the driver should take over (a part of) the driving task again. The differences between assisting overrulable and assisting non-overrulable can become a little vague since assisting non-overrulable systems should be turned off by the driver in cases of emergencies or whenever the vehicle must stop or leave a dedicated lane.

Most researchers see an evolutionary path over these categorisation axes for the development and introduction of driver support systems (e.g. Hall, 1995; Stevens, 1995; Van Arem, 1996). Such an evolution mostly runs from the introduction of overrulable assisting support systems for the longitudinal driving task through lateral control systems to the introduction of dedicated lanes and non-overrulable full automation of roads.

Results from a recent Delphi study aimed at clarifying initial market prospects and barriers for introduction of different driver support systems, show experts do not see a future concept of a fully automated and integrated transport system before the first half of the 21st century (Marchau & van der Heijden, 1997).

The next sections of this chapter describe several driver support systems according to the proposed evolution along the categorisation axes: longitudinal support, lateral support and the autopilot. The expected impacts on traffic safety, road capacity and driver comfort as well as driver behaviour reactions and acceptance issues are discussed with respect to each system.

2.3 Speed and headway support (longitudinal control)

2.3.1 Adaptive or Intelligent Cruise Control (ACC)

Adaptive Cruise Controls (ACC's) are currently in development in the automotive industry and are actually on sale in the higher market segment of passenger cars (e.g. the BMW 700 series). An ACC is a system that is capable of maintaining a certain headway behind slower vehicles ahead, in addition to the conventional Cruise Control function of controlling a vehicle's speed at a driver-chosen value. This headway keeping is done by means of adjusting the speed of the car in order to prevent exceeding the programmed headway of the system.

An ACC is a system that does not communicate with other vehicles or roadside systems. Therefore an ACC is applicable in mixed traffic flows: vehicles with and without the system can use the same road. This is one of the reasons why this system may develop earlier on the evolutionary path than systems that do require roadside communication.

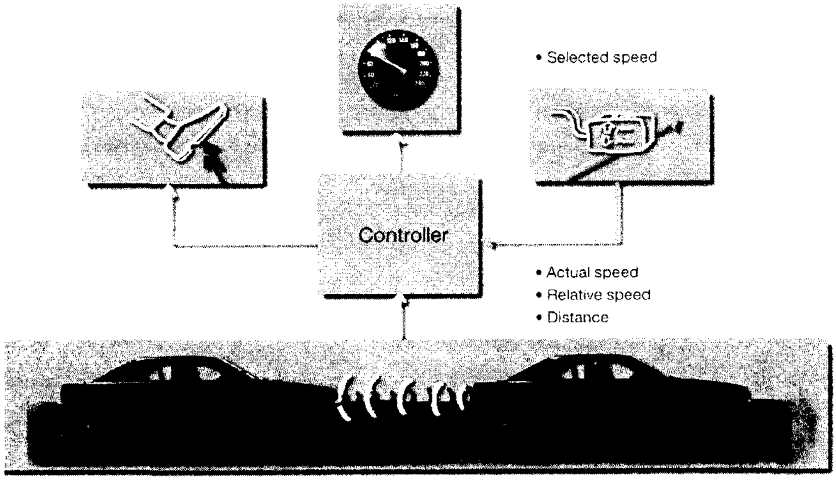

Figure 2-1. Schematic representation of an Adaptive Cruise Control (ACC). A sensor continuously measures the distance to the preceding vehicle, and actual and relative speed. The controller compares this information with the selected speed and preset headway. When necessary, speed is adjusted by deceleration or acceleration.

Since the United States has the highest percentage of normal cruise controls and the largest amount of highway driving compared to Europe and Japan, one would normally expect it to be the first of the three to have Adaptive Cruise Control on the market, but instead it will be the last of the three. This is because in Europe, more attention has been given to adaptive cruise controls. The development of a range and speed control system for use on motorways originated from the research project PROMETHEUS (PROgraMme for a European Traffic with Highest Efficiency and Unprecedented Safety) and will be fitted to future models in a BMW-specific design.

Expected effects

With respect to traffic performance, an ACC could contribute to an improvement in two ways. First, the system may enable driving at shorter mutual distances and at higher speeds than in cases with human operation. This could result in an increase in roadway capacity (Van Arem et al., 1996). It has to be noted however that the target headway of the first ACC is expected to be 1.5 s (Mauro, 1993). This would imply that mutual distances would certainly not be shorter: existing motorway headways below 1 s are quite frequent. This would imply that a decrease in roadway capacity is also possible (Minderhoud, 1996). Second, ACC systems could contribute to a more stable traffic flow, by means of a smoother acceleration and deceleration profile, thus reducing speed variation amongst vehicles and reducing the occurrence and/or severity of shock waves. This harmonisation of traffic could contribute to a higher throughput and safety.

The magnitude of this headway has important safety and capacity implications. Large headways would ensure that if the lead vehicle suddenly stops, the ACC would always be able to bring the car to stop safely, regardless of the deceleration rate of the lead vehicle. However, as was stated above, large headway's invariably lead to lower traffic density and decreased highway capacity. Such a trade-off suggests that ACC's to be marketed in the future are likely to be those with small headways, just large enough to assure that they can bring equipped vehicles to a safe stop when the lead vehicle suddenly brakes, but not large enough to result in a significant loss of motorway capacity. It is even conceivable that ACC's may be designed to allow drivers to select their own headway according to prevailing driving condition and driving style (Chira-Chavala & Yoo, 1994).

With respect to traffic safety, a more stable traffic flow is expected to improve traffic safety. A further improvement can be expected from the fact that the human reaction time is eliminated. Again, there are also possible drawbacks (Van Arem et al., 1996). The early ACC systems will have a limited sensor range in the order of 130 m, which is much less than human observation in good visibility conditions. Also a restriction of the current prototypes is that they can only realise moderate acceleration and deceleration levels, i.e. they cannot perform emergency braking. For example the Daimler-Benz prototype (Müller & Nöcker, 1992) only produces accelerations up to 1.2 m/s^2 and declarations up to 1.8 m/s^2. So the driver has to take over in situations the ACC cannot cope with. In Morello et al. (1994), an ACC design of a constant headway type of 1.5 s is assumed, and a maximal deceleration of -2.5m/s^2. Regarding these relatively low deceleration levels, ACC's can only serve as a comfort device; they are obviously not intended for emergency braking. Reactions in emergency situations still remain a task for the driver, which could influence traffic safety in a negative way, when drivers are relying too much on the system capabilities.

To summarise, ACC's are potentially systems that may improve traffic safety and capacity by keeping a constant headway to the vehicle in front; thereby also improving traffic flow and harmonisation. To what extent ACC's will realise these goals depends on technical possibilities, such as deceleration level and headway magnitude, but more important in the success of these systems is the way in which drivers will use the system, their acceptance and their reaction in terms of driver behaviour.

2.3.2 Intelligent Speed Adapter (ISA)

An Intelligent Speed Adapter (ISA) takes into account local speed restrictions, and adjusts the maximum driving speed to the posted maximum speed. ISA's require communication between the vehicle and a suitable information source. For exchange of information about the road class or local restrictions, one option is to equip traffic signs with transmitters, beacons or tags. At the moment a car passes such a sign, the new speed limit is to be conveyed to the vehicle in one way or the other. Examples of experimental car-infrastructure communication can be found in Sweden (Nilsson & Berlin, 1992, Palmquist, 1993) and the Netherlands (De Waard & Brookhuis, 1995, 1997). Another option would be an advanced map-based information system, mediated by Global Positioning System (GPS). GPS is a satellite-based navigation system to determine the three-dimensional position, velocity and time.

In general, an intelligent speed limiter is an intrusive system that restricts speed control, i.e. the device sets the maximum possible driving speed. A less intrusive device is a system that provides the driver with feedback about local limits, for instance, on the gas pedal. An active gas pedal increases the counterforce if the driver is driving too fast (Godthelp & Schumann, 1991). In principle, such a speed limiter leaves the driver in control, while the feedback provided in case of a speed violation is highly compelling. Feedback could also be presented in the visual modality, on a small display Brookhuis & De Waard, in press). Acceptance of the feedback type systems can be expected to be higher than of a strict, standard speed limiter, because behaviour is less restrained. Results from a questionnaire survey demonstrate that a slight majority of people consider an indicator of speed-limit violations useful, while only 35% of the respondents were of that opinion with respect to a speed limiter (Hagen & Fokkema, 1990). A survey study of Timmermans (1997) shows that drivers are less positive about the more restrictive ISA systems. The respondents preferred an ISA system with the possibility of a personally set maximum speed.

Expected effects

ISA systems will influence traffic safety in a positive way because speed limits will be exceeded less frequently or even not at all. However, speed violations can sometimes be advantageous for traffic safety. It is conceivable that there are instances in which a critical overtaking manoeuvre could be faster and more safely performed if the speed limit was exceeded for a short while (Brookhuis & De Waard, in press). Effects on road capacity are not expected, except that these systems may contribute to a more stable traffic flow (harmonisation). Also effects on driver comfort remain unsure when we look at the questionnaire results from above.

2.3.3 Collision Avoidance System (CAS)

Front-to-rear-end crashes involving two or more vehicles currently represent approximately one-fifth of all collisions. Driver inattention is believed to be the largest factor in these crashes (Dingus et al., 1997), and the next most important factor is 'following too closely' (Knipling et al., 1993). Collision Avoidance Systems (CAS) have been proposed as a potential remedy to this type of accident (Hancock et al., 1996). Because it can be calculated that a driver will be involved in a rear-end crash every 25 years on average, ideally a CAS should signalise only that case. This indicates that collision warnings of such a system should rarely occur. Even then, however, it will be clear that superb discriminative power will be required from a CAS. Such power is probably unattainable because it would demand complete knowledge of what distinguishes collision from non-collision configurations in traffic well before the collision happens (Janssen & Nilsson, 1993).

Janssen (1995) describes a Collision Avoidance system that was implemented in a prototype intelligent vehicle. The system uses a time to collision (ttc) criterion of 4 s. Ttc is defined as the time required for the following vehicle and the lead car to collide if they were both to continue at their present speed. Input to the CAS is provided by radar measurements of the range and relative speed of preceding vehicles. When the ttc-criterion is met the driver experiences an increased counterforce on the accelerator pedal, which can be overruled by pressing more forcefully. It is also conceivable that the system action cannot be overruled by the driver.

Expected effects

By avoiding collisions these systems are intended to increase traffic safety. The available information shows that it is questionable if Collision Avoidance systems can always make this promise come true. The Delphi study by Marchau & van der Heijden (1997) shows that there are varying expectations among experts about the systems' capabilities to detect obstacles and make decisions on appropriate actions. Some experts indicated that detection of small objects is still difficult. Others indicated that these systems would initially detect only moving vehicles and motorcycles and no stationairy objects. Reliability, false alarms and liability are too serious problems for near term deployment of Collision Avoidance Systems. The potential safety improvements were considered to be certain by the expert panel. When the false alarm rate can be kept very low, driver comfort can be increased because drivers don't have to be very alert on rear-end collisions anymore. With respect to driver acceptance of CAS, Nilsson & Alm (1991) tested different collision avoidance systems and found that take-over of control in cases of very short headways to a car in front was less appreciated than warning or suggestions of the appropriate action.

2.4 Lateral position support (lateral control)

Lateral position support systems are designed to help the driver to keep the vehicle in his lane in order to decrease the chance of a lane-straying accident. By monitoring the borderlines, the system can give a warning or actually correct the steering wheel position when the vehicle is about to cross this line. The systems are to a large extent dependent on road-side information; the course of the road must be sufficiently marked by e.g. lines, reflectors or radio-signals, depending on which type of lateral control system is used (Gundy & Kaptein, 1994). Three types of current lateral support systems are shortly discussed.

- LACOS (LAteral COntrol Support)

Whenever a LACOS equipped vehicle approaches the lane delineation within a determined margin, and a vehicle is detected in that lane, a corrective or feedback signal on the steering wheel is given. Margins are expressed as time-to-line-crossings (TLC) of 1 s or less. The drivers' attention is supposed to be (re)directed to the vehicle's position and initiate corrective actions (Brookhuis & Soeteman, 1998b).

- Dead Angle Alert

A more specialised form of a lateral position support system is the so-called dead angle alert or blind spot monitor. This system detects potentially hazardous traffic coming from behind. The system monitors the blind spots and warns the driver whenever another vehicle encroaches upon this area. Possibly drivers will decrease their attention for traffic coming from behind, because they expect the system to cover this dead angle. This could be especially dangerous when slower moving objects (like cyclists) are not detected (Gundy & Kaptein, 1994).

- Reverse Parking Aid

These systems detect obstacles behind a vehicle (e.g. using radar). They inform the driver of the distance to obstacles immediately behind and to the side of the car. They can depict the car and adjacent cars in a plan diagram, or sound a variable signal (e.g. a tone increasing in pitch) to indicate closing distance. Collision chance when moving backwards is possibly reduced (Gundy & Kaptein, 1994).

Expected effects

The possible benefits in terms of traffic safety of lateral position support systems are clear. The systems correct inattention or misperception leading to a possible threat of collision with a vehicle in an adjacent lane (Brookhuis & Soeteman, 1998b). Lateral support systems facilitate the drivers' task and may therefore increase driver comfort. The systems are not expected to have effects on road capacity.

2.5 Autopilot (both longitudinal and lateral direction)

2.5.1 SAVE (Automatic Control Device)

The SAVE project aims to provide a system for effective assessment of the driver state and vehicle control in emergency situations. The Automatic Control Device (ACD) is a major part of the SAVE system that will control the vehicle once the driver is no longer capable to do so. This means that the driver will be taken out the control loop (Brookhuis & Soeteman, 1998b). Onboard driver monitoring techniques activate warnings to other road users and instigate a safe deceleration and lane-change strategy. Whenever a driver suddenly became ill, and was no longer capable of bringing the vehicle to a safe stop, the ACD function could take over completely. Immediate communication to an emergency centre follows.

Expected effects

The critical situations in which the system would operate mean that automatic action of the system is likely to reduce the risks to other road users, should a driver's ability to control the vehicle become suddenly and dramatically impaired. Drivers would probably feel more comfortable in a vehicle equipped with ACD (Brookhuis & Soeteman, 1998b).

2.5.2 Automated Highway System (AHS)

In a fully automated highway system the vehicle will be guided by the road infrastructure rather than by the driver. The American PATH project (Partners for Advanced Transit and Highways) developed a chain of cars that is able to run autonomously on a special track. Special motorway lanes, dedicated for this purpose are needed. They have magnets installed down the centre of the track and are equipped with vehicle-to-roadside communications. The cars use magnetometers to detect the dense series of magnetic markers buried in line in the road pavement for lane keeping, short-range forward looking radar for headway control, and digital radio local network for inter-vehicle communications. In this way it is possible to have 'platoons of cars' driving behind each other with small headways at high speeds. When the vehicle reaches the exit selected by the driver, it will be moved into a transition area where control will be returned to the driver.

This train of autonomous vehicle has been demonstrated in August 1997 on a dedicated lane near San Diego, and in Rijnwoude in June 1998 (see figure 2.2).

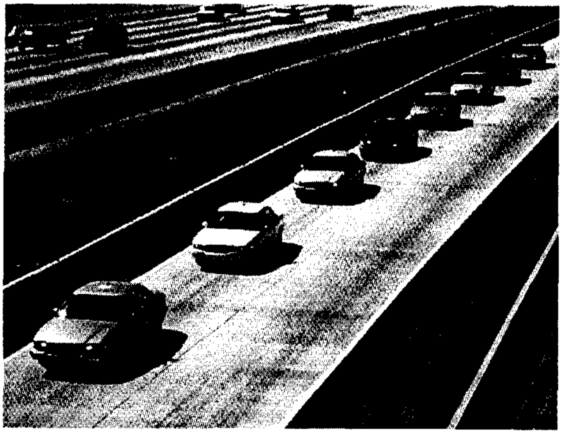

Figure 2-2. California PATH demonstrating a fully automated platoon of eight Buick LeSabres during Demo '97 in San Diego.

Expected effects

The automated highway system can increase road capacity considerably because more vehicles can be accommodated on the motorway. However, the way in which for instance junctions, merges and ramps are designed and controlled, together with safety restrictions leading to larger headways, may reduce theoretical capacity gains (Marchau & van der Heijden, 1997). Further benefits include a considerable enhancement of efficiency, reduction of fuel usage of 30% and the concomitant reduction in emissions (Brookhuis & Soeteman, 1998b). As long as AHS operates flawlessly, the benefits of this system are obvious as far as traffic safety is concerned. But the introduction of AHS will add to the technological complexity of the traffic system, which increases the likelihood of failure of at least one of the system's components (Janssen et al., 1992). Obviously, there is no way of guaranteeing that a car or any other part of the system will not fail in the AHS (Hitchcock, 1991). In principle, when a system fails to work, feedback should be provided to let the operators know they cannot rely on the system. The main reason for warning operators is that automated systems can lead to overreliance or complacency. De Waard et al. (1997) tested this overreliance on the AHS in a simulator study, where the automated system failed to function properly in an emergency situation. The driver actually had to take over speed control to avoid an uncomfortable short headway of 0.1 m. They found that in this situation only half of the participants took over control. They concluded that if drivers are to reclaim control in cases of system failure, then the driver should not have a passive role in the system. Also, the status of automation should be clear and system failure should be salient (De Waard et al., 1999).

Only after system reliability is ensured and driver liability is ruled out, will driver attention to the system become formally superfluous. One of the basic questions then will be whether driver intervention should be allowed at all (Tsao et al., 1993). There are serious doubts that it will be acceptable for the driver to be totally without control (De Waard et al, 1997).

2.6 Conclusions

Based on an assessment of potential driver support systems along a hypothesised evolutionary path, it is concluded that the longitudinal driver support systems have the most promising characteristics to contribute to improved driver comfort, traffic safety and efficiency without infrastructural adaptations (see also Minderhoud, 1999). Furthermore, it is one of the most realistic driver support forms. As one of the first steps on the evolutionary path, different versions of Adaptive Cruise Control systems are already available.

ACC's have been engineered to improve traffic safety and efficiency, because of the constant and safe headway they keep behind a lead car. The extent to which ACC systems will realise these goals depends among other things on the acceptance by the public and how they affect driving behaviour. As was stated in recent Dutch Automatic Vehicle Guidance government plans (Businessplan Automatische Voertuig Geleiding, 1998), all possible forms of AVG will bring about changes in driver behaviour, so prototypes of these systems should be tested thoroughly on their behavioural effects and the implications for traffic safety, road capacity and driver comfort. The Organisation for Economic Co-operation and Development (OECD, 1990) has identified behavioural adaptation to be a significant issue for interventions which affect vehicle operation. The OECD (1990) contends that "drivers employ the vehicle technology available to them in order to suit their driving purpose, motivation, driving style and current physical process".

The research described in this thesis aims at the assessment of driver behaviour and acceptance as a response driver support systems focusing on the longitudinal driving task, i.e. adaptive cruise control.

3. Literature survey on driver behaviour models

In order to think about the implications of driver support systems for driver behaviour, it is necessary to assess the factors that play a role in driver behaviour. Consequently this literature survey is aimed at psychological modelling of the driver. It includes a description of (some of) the existing driver behaviour models and gives the most important implications of those models towards the implementation of driver support systems. Also a hierarchical framework of driver behaviour is presented in which cognitive constructs such as driver needs are connected to the low level operational driving tasks. With the aid of this hierarchical driver model, predictions can be made about how automation of particular driving tasks may influence overall driving behaviour and to what degree these may be driver dependent. The research described in this thesis is based on these predictions, and investigates the aspects of drivers' needs and their reaction to driving with a driver support system (i.e. Adaptive Cruise Control).

3.1 Introduction

A considerable number of models of driver behaviour and traffic safety have been developed, based on different theories of human behaviour, and focusing on different aspects of the driving task. Within the cognitive framework, driving can be generally described as consisting of the following tasks (Kuiken & Heijer, 1995):

- drivers must perceive relevant elements in the traffic environment;
- they must assess the task requirements and decide on a suitable response;
- they must implement these responses as actual behaviour;
- monitor the consequences of their actions;
- and, if needed, adjust their behaviour.

In other words: driving can be seen as a closed loop control process. The driver perceives and interprets information, determines and initiates a response, then resumes the process by interpreting the feedback in relation to any discrepancy from a goal state, in order to sustain a margin of performance (Ward, 1996). If all the phases are run through, the cycle is said to be a closed loop process. However, there are also instances in which there is an open loop process. In that case, the last two phases, evaluation and adjustment with regard to the present activities do not take place. Especially in tasks that are highly automated, tasks that are originally performed in a closed loop cycle will become performed in an open loop style. This means that sometimes necessary adjustments are not made, and that the control the individual exhibits is limited to the generation of initial responses.

However, it has become clear that the driving task is too complex to be considered a purely closed-loop task (e.g. Godthelp et al., 1984; Verwey, 1994). Vehicle control does not always require, or allow, immediate path-error corrections. Owing to the complexity of the task, drivers may be forced to pay attention to other aspects of the driving task and may decide to undertake or not undertake certain actions. So task performance may also take place in open loop control, i.e. without a continuous monitoring and responding to feedback. Open loop control may occur in the instance in which (parts of) the driving task have become automated.

3.1.1 Structure of the chapter

There is a range of psychological models, either specific driver behaviour theories or generally task performance theories, that can to some degree predict driving behaviour. Models of driving behaviour are placed within a hierarchical structure of driving tasks that is discussed in the next section (Michon, 1985; Janssen, 1979). These models each aim at different aspects of this structure and will be discussed in the following sections. At the end of each section implications of the models will be discussed with regard to the implementation of driver support systems. In section 3.6, aspects of the discussed models are integrated into a hierarchical framework of driver behaviour with which predictions can be made about how automation of a particular driving task may influence driving behaviour.

3.2 A hierarchy of driver tasks

The driving task can occur at different levels of performance control. The more the driving task occurs in an automated fashion, the less attention it will demand. The degree to which levels of demands on attention differ, is dependent on the type (regulation level) of performance control.

Rasmussen (1983) distinguished three levels of control of task performance. These are the knowledge-based level, the rule-based level and the skill-based level. This general hierarchical classification can be used as an instrument to investigate a complex task like driving. The different levels of human performance show how much attention is needed to perform different tasks.

- At the highest *knowledge-based level*, human behaviour is goal-controlled and depends upon feedback correction (i.e. a closed-loop process). This is the level at which people develop new ways of problem solving. It requires attention and effort. To be useful for reasoning and computation, information from the environment must be perceived as *symbols*. Symbols are defined by and refer to the internal conceptual representation that is the basis for reasoning and planning.
- When the task or environment becomes more familiar, human behaviour is not goal-controlled anymore, but oriented towards the goal and controlled by a set of rules that has proved successful previously. At this *rule-based level* courses of actions (rules) are available and an appropriate action has to be chosen. The process of choosing a rule may be more or less conscious, but once a rule is chosen the actions are carried out automatically; so less attention is required compared with the knowledge-based level. The execution of the rules is monitored and compared against the task goals. The outcome of this comparison is transferred to the knowledge-based level. Derivations trigger rule adjustment or goal adjustment. The control process at this level of task performance is mostly closed-loop and information from the environment is perceived as *signs*. Signs serve to activate or modify predetermined actions or manipulations and refer to actual situations or proper behaviour.
- At the lowest *skill-based level*, highly practised routines are carried out; actions are completely automated. This means that they are not continuously monitored, and therefore there is no continuous feedback mechanism in this open-loop control mode. The information from the environment is perceived as *signals*, which have no meaning. Only something going wrong in this open-loop mode triggers task performance to be carried out at a higher level.

The distinction between signals/signs/symbols is not dependent on the form in which the information is presented but rather on the context in which it is perceived, i.e. upon the intentions and expectations of the perceiver (Rasmussen, 1983).

Michon (1971, 1985) and Janssen (1979) proposed a hierarchical structure of the driving task in which driving behaviour is modelled in a hierarchy of three types of tasks:

- At the *strategical* or navigation level drivers prepare their journey, it defines the general planning stage of a trip, including the determination of trip goals, route, modal choice (i.e. mode of transportation), trip time and speed. Considerations about costs and risks play an important role here. Decisions are influenced, on the one hand by goals and attitudes, and on the other hand by the amount of information drivers have about general traffic conditions and their own state.
- At the *tactical* level drivers exercise manoeuvring control, allowing them to negotiate the directly prevailing circumstances (e.g. obstacle avoidance, gap acceptance, turning, and overtaking). Here drivers are primarily concerned with interacting with other traffic and the road system. This manoeuvring behaviour is mostly dictated by the current situation, but also by the goals set at the navigation level.
- The *operational* level involves the elementary tasks that have to be performed to enable manoeuvring the vehicle. It involves the control of the vehicle by using car controls and pedals, the steering wheel etc. Most of these elementary operation tasks are performed automatically and unconsciously, like changing gears.

The control hierarchy of driving has been related to Rasmussen's taxonomy, as shown in table 3-1. For experienced drivers, most driving tasks cluster in the three cells on the diagonal that runs from the upper left to the lower right box. Knowledge-based behaviour is involved at the strategical level, rule-based behaviour at the tactical level, and skill-based behaviour at the operational level. As shown by the examples in other matrix cells, exceptions reflect differences between skilled and novice performance, and between familiar and unfamiliar situations. For example, novice drivers initially use knowledge-based behaviour to shift gears, while experienced drivers use skill-based behaviour (Hale et al., 1990). In fact, Shinar et al. (1998) show that well beyond the first year of driving, manual gear shifting appears to be a controlled process, one that takes a significant amount of time and places significant demands on the driver's attentional capacity.

Table 3-1: Relation between performance levels of control (vertically) and hierarchy of driving tasks (horizontally). Adapted from Hale et al. (1990).

	Strategical tasks	Manoeuvring tasks	Operational tasks
Knowledge-based	Navigating in unfamiliar area	Controlling skidding car	Novice on first lesson
Rule-based	Choice between familiar routes	Passing other vehicles	Driving unfamiliar vehicle
Skill-based	Route used for daily commute	Negotiating familiar intersection	Vehicle handling in curves

3.3 Strategical tasks: motivational models

In motivational models driver behaviour models psychological characteristics or motives play an important role. The driver is seen as an active decision maker or information seeker (Gibson, 1966), rather than the passive responder implicit in many information-processing models. Motivational models address driving in its entirety and emphasise the inherent variability in driving (Ranney, 1994). Most motivational models have focused on how road users deal with risk (Wilde, 1982; Summala, 1988; Fuller, 1984), but aspects like pleasure, thrill seeking, competitiveness (e.g. Evans, 1991), and social resistance and deviance (French et al., 1993) may also play an important role. In these models it is assumed that the driver has a goal or a set of goals that can be written as a utility function. The next sub-sections describe the different motives or goals a driver can have, a theory on motivation, and decision-making behaviour. In the last sub-section a number of motivational models focussing on risk handling and threat avoidance are discussed.

3.3.1 Goals, needs and attitudes

According to Rumar (1993), the motives and the goals for travelling are the basis for needs. The primary goal for road users is to reach their destination, but they do not accept that goal at any price. The driver requires a certain time, speed, safety, economy and comfort. These are called the secondary goals, or needs.

Rothengatter (1988) examined the relationship between speed choice and motivational factors within the framework of Fishbein and Ajzen's model of reasoned action (1975, see also below). It was found that speed choice is determined by four motivational factors: pleasure in driving, risk, travel time and costs. Pleasure in driving proved to be the strongest determining factor of speed choice, in that the subjects with the highest speed scored highest on pleasure in driving. However, pleasure in driving was also related to the top speed of the vehicle and thus to vehicle characteristics.

Summala (1988) identified a tendency towards higher speeds, reluctance to reduce speed, conservation of effort and habit as motives in driving. Drivers may actually attempt to minimise their allocation of attention to driving, to free up resources for non-driving-related activities.

French et al. (1993) investigated the relationship between decision-making style, driving style and accident rates. Speed is described as an aspect of driving style together with more motivational concepts such as social resistance and deviance. This indicates that the concept of driving style is not clearly defined since it mixes overt behavioural manifestations with covert motivational constructs. West et al. (1992) conclude from their finding that a relationship exists between self-reported behaviour and global decision-making style, that offers the possibility for important driving behaviour to be understood in terms of more generally applicable traits that drivers may have. At a theoretical level it provides a way of linking theories of driver behaviour with more general theories of cognition and motivation.

Fishbein and Ajzen (1975) presented a model of reasoned action, which has been used extensively to study the motivations that underlie specific behaviour. According to this model, behavioural intention, and hence behaviour, is determined by the person's *attitude* to behaviour and by the *subjective norm.* Attitude refers to the evaluations of the consequences of performing the behaviour. Subjective norm is a product of belief about significant others' expectations (normative belief), and the motivation to conform to them (motivation to comply) (Forward, 1997). According to Hogg and Abrams (1993), normative influences are based on pressure to comply. It results from the individual's need for social approval and acceptance.

The theory of planned behaviour (TPB) represents an extension of the original theory of reasoned action (Ajzen, 1985, 1988). The TPB includes a third determinant of behavioural intention; *perceived behavioural control* (i.e. the degree of control the individual perceives that he or she has over successful performance of the behaviour). It is assumed that people are unlikely to intend to perform behaviours over which they think they have no control. Perceived behavioural control differs from Rotter's (1966) concept of *locus of control* in that the latter is concerned with generalised beliefs about control over outcomes, whereas the perceived behavioural control variable measured in the TPB model is tied to a specific behaviour in terms of time, action, target and context (Parker et al., 1992). In the context of driving behaviour, the model has been applied to study the attitudinal determinants of a range of driving violations, including tailgating, risky overtaking and speeding (Parker et al., 1992, 1995).

According to Parasuraman (1997), attitudes toward automation vary widely among individuals and understanding these attitudes constitutes a first step toward understanding human use of automation. However, attitudes are not necessarily linked to behaviours that are consistent with those attitudes. Several studies found no relationship between attitudes toward automation and actual reliance on automation during multiple-task performance (Riley, 1996; Singh et al., 1993). However, there may be differences between general attitudes toward all automation and domain specific attitudes like driving task automation.

3.3.2 Decision making behaviour

In decision-making theory the driver is assumed to have a goal that can be written as a utility function in which desired quantities have positive signs and unwanted consequences have negative signs. The theory indicates that the driver will strive to maximise this utility function (e.g. Evans, 1991). A problem with most decision models is that they assume complete rationality of the user and that users have access to all different aspects of information when making a decision. People do not always make rational decisions and they don't have access to complete information. Simon (1957) introduced the *satisficing-concept* as opposed to *optimising* decision-making. In satisficing decision making humans choose the first alternative that is acceptable. In natural and often complex situations humans adopt those strategies that are adequate rather than optimal. There may not be enough time available to evaluate all alternatives, or only incomplete knowledge of the situation is available, which renders comparison of all alternatives not justifiable. In satisficing decision theory ***good enough*** is defined as the set of decisions (actions) for which the total benefit is greater than the total cost (Goodrich et al., 1998). One of the advantages of satisficing decision making over optimal decision making is that alternatives can be evaluated independently to assess whether they are acceptable or good enough. An immediate consequence is that an exhaustive search is generally not required because upon finding the first acceptable alternative, the search can be terminated, thereby promoting efficient use of limited attentional resources. This is not the case in optimal decision making since all alternatives need to be compared in order to find the best one (Boer et al., 1998).

3.3.3 Risk handling

A number of motivational models focus on drivers' risk handling and threat avoidance, for example Wilde's (1982) risk homeostasis theory, Näätänen and Summala's (1974) zero-risk theory, and Fuller's (1984) threat-avoidance theory. All these theories assume that drivers select the amount of risk they are willing to tolerate in any given situation. The risk associated with possible outcomes is seen as the main factor influencing behaviour. However, these models also assume that drivers do not generally make a conscious analysis of the risks associated with alternative outcomes (Ranney, 1994).

Wilde's (1982) Risk Homeostasis Theory (RHT) is based on the assumption that the level of accepted subjective risk is a relatively stable personal parameter. Individual differences in this model refer to differences in motivational state that may affect the target level of risk. The RHT consists of an individual model of driver behaviour and an aggregate model that relates driver behaviour to accident rate. In the individual model, the driver is assumed to have a target level of risk that represents the amount of accident risk the driver accepts and wants to attain. When there is a discrepancy between perceived risk and target level of risk, the driver makes a behavioural change. Aggregated over all road users, these behavioural changes or adjustments will produce a fixed rate of accident frequency and severity. An important implication is that drivers will compensate for perceived traffic safety improvements by adjusting their driving behaviour to re-establish the target level of risk. Very typical of homeostatic processes is variation in the level of the target. So, homeostasis does not mean constancy. A homeostatic process makes it possible to extract long-term steadiness from short-term fluctuations (Wilde, 1994).

A lot of controversy has arisen over Wilde's hypothesis in the sense that safety improvements will not work unless it affects the target level of risk (McKenna, 1988). The ability of drivers to monitor accident risk has been questioned and the assertion that drivers experience or accept risk has been challenged (e.g. Evans, 1991). The plausibility of seeking some level of risk has been seriously doubted and, according to several authors, drivers seek the lowest possible, or zero, level of risk.

Näätänen and Summala (1974, 1976) developed the zero-risk theory. An important difference with the RHT is that in this theory the driver is assumed to accept no risk at all, that is, the target level of risk is zero. The subjective risk monitor is a crucial element in this model. It was conceptualised as a monitor that generates different degrees of subjective risk depending on the present or expected traffic situation. Activation of subjective risk inhibits ongoing behaviour in the sense that it results in behaviour such as slowing down. In later publications (Summala, 1988), the concept of safety instead of risk was stressed; drivers control and maintain safety margins, since normally the driver gives no consideration to risk.

Fuller (1984) raises the question as to how subjective risk reactions can be an important determinant of driver behaviour at all when the subjective risk of an accident is zero for most of the time. In his threat-avoidance model, drivers are believed to be motivated to avoid aversive stimuli or situations. The concept of risk is not used at all. Fuller talks about potential aversive stimuli or threats because the driver's own actions determine whether or not interactions with the road environment will be punishing, stimuli in the road environment have an aversive potential. Because of the conditioning of anticipatory avoidance responses to particular discriminative stimuli, road users have learned specific choice production rules that generally lead to rewarding choices in that they prevent the experience of risk.

When comparing the three models of risk handling, the most salient difference is between risk homeostasis on the one hand and the other two models on the other (Heino, 1996). From these risk handling theories, it can be concluded that the best traffic safety measures are those that decrease objective risk but increase subjective risk. It has been found that drivers tend to adapt to diverse driving conditions such as road surface, the presence of ABS (Anti-lock Brake System), visibility, and numerous other factors that may affect accident likelihood (Heino, 1996). Many authors (e.g. Howarth, 1987) have stressed the potential safety benefits of decreasing objective risk without altering subjective risk, or of increasing subjective risk without changing objective risk. An example can be found in the painting of a geometric pattern of bars with decreasing spacing on the road to reduce speeds by convincing drivers they are travelling faster than they actually are.

3.3.4 Implications for driver support systems

In conclusion, a range of motivational factors may play a role in a driver's behaviour on the road and his/her reaction to the automation of the driving task. The models discussed in this section show that at the strategical level of driving behaviour it is important that driver support systems match the needs of a driver. These needs are concerned with risk, pleasure, expediency, costs and speed. They form the personal weights in the decision making utility functions of drivers and may influence the attitudes of drivers towards automation of the driving task.

In line with the risk handling theories, it can be expected that, to the extent driver support systems are perceived as a safety benefit, they may effect a reduction in the perception of driving risk with the system (Ward et al., 1995). In accordance with the tenets of Risk Homeostasis Theory, this perceived reduction may precipitate a higher risk driving style through higher speeds and shorter headways (Ward, 1996).

Driver support systems may be expected to directly influence the degree of control the driver has over his or her driving task. According to the theory of planned behaviour drivers are unlikely to intend to perform behaviours over which they think they have no control. It can be expected that drivers will have problems with these kinds of systems if they are a threat to driver control.

3.4 Tactical tasks: skilled performance models

Skilled-performance models assume that drivers acquire knowledge and skills (i.e. vehicle control skills) through training and their participation in traffic, and they develop mental representations of traffic situations and the road. These specific skills and representations of traffic situations, road and rules are assumed to be the major determinants of behaviour. Due to the enormous range and complexity of traffic situations, drivers must be able to categorise those features that are functionally similar. The advantage of this categorisation or pattern recognition is that it will speed up the processing of information. Drivers must also have basic knowledge about different traffic situations, frequently referred to as scripts, plans, or scenarios (Schank & Abelson, 1977). This makes it possible to predict what to look for in different categories of traffic situations, where to look, and when to look for it. From these observations drivers must be able to predict the future behaviour of other road users. Based on these predictions they must decide on suitable responses to the predicted behaviour of other road users (Rothengatter et al., 1993).

3.4.1 Predictive behaviour and mental models

In the driving behaviour model of Heijer and Polak (1995), the central focus is on the interaction between the driver and the actual traffic environment. Internal models or representations also play an important role. Heijer and Polak distinguish between two behaviour models; *predictive behaviour* and *tracking behaviour*.

- An important condition for *Predictive* behaviour is that the driver has built one or more internal models of the behaviour of other traffic participants. This internal model is built up by experience. A second condition is that there must be enough time to perceive the other road users, to apply the internal models and extrapolate appropriate behaviour; so changes in the traffic environment must be sufficiently 'slow'. When these conditions are met the driver can generate useful short-term predictions and compensate for small errors in the prediction. Predictive behaviour is linked with actions that are related to speed choice, following times and with special manoeuvres like lane changing and passing other cars.

- When perception time is limited, the driver gives up predictive behaviour and switches to *Tracking* behaviour. This tracking behaviour is characterised by merely following traffic participants in front of the driver. The driver will concentrate on reactive error compensation because there's no time to make predictions about the behaviour of other drivers. Tracking behaviour is less safe compared to predictive behaviour, because it makes the driver more susceptible to traffic disturbances and continuous attention is needed.

Huguenin (1988) sketched an action-theoretical model of driver behaviour, in which the *actual traffic situation* is an important determinant of the actions that are taken by the driver. Emphasis on driver action is based on the idea that behaviour is consolidated in actions (action is goal-directed behaviour), and that behaviour cannot be described in general terms, but only by reference to specific situations. In this model a distinction is made between routine traffic situations involving habitual behaviour patterns and complex situations that demand explicit and reasoned choices between alternative responses. Van der Hulst (1999), however, argues that instead of a categorisation of traffic situations as either routine or complex, perhaps a better classification would be whether a situation is predictable or not. It can be assumed that the expectations of the driver and the predictability of the situation play a central role both in tactical decisions such as speed choice and in reactions to discrete events.

Expectations and predictions are closely linked to the concept of mental models, since prediction requires a model of the future. Johnson-Laird (1983) used the term mental model to refer to an organised structure of task-relevant information that allows mental simulation of processes, causes, or events in the environment (see Smith & Hancock, 1995). According to Rouse & Morris (1986) a mental model is an individual's cognitive representation of how a system operates. Mental models enable an individual to describe, explain, and make predictions about system operations. Norman (1983) argued that mental models require time to evolve, and they may be incomplete and imprecise. Also, mental models about particular systems may be structured from knowledge of other systems, from prototypes, or even from faulty information.

Hughes & Dornheim (1995), who described the effects of the so-called glass cockpits in air traffic also stress the importance of predictions and mental models. Glass cockpits are modern airline transports equipped with electronic flight and engine systems instrumentation. The researchers described some accidents and incidents where the aeroplane surprised the pilot or the pilot did something that the aeroplane did not expect. Mostly pilots were confused about what the automation was doing. They concluded that pilots do not always have a good mental model of what the computerised flight systems are up to in all circumstances. The breakdown in communication between the pilots and automated systems is occurring as computers are becoming more complex and as they are given more authority in the cockpit.

3.4.2 Situation awareness

In the pilot case described above, the human operators overseeing the automated systems were unaware of critical features of the systems they were operating. They were unaware of the state of the automated system and of the aircraft parameters for which the automation was responsible. Each of these problems can be directly linked to a lower level of *situation awareness*, or the pilot's internal mental model of the world around him or her (Endsley, 1996). Endsley (1988) defines situation awareness at three different levels: (1) the perception of the elements in the environment within a volume of time and space, (2) the comprehension of their meaning, and (3) the projection of their status in the near future. This last level, in particular, specifies the link between situation awareness and mental models. According to Smith and Hancock (1995), however, equating situation awareness with mental models appears to confound knowledge with process. They define situation awareness as adaptive, externally directed consciousness. It involves the projection of suitable actions and directs behaviour. Situation awareness in driving involves the continuous updating of knowledge about the position and behaviour of other road users, and confidence in the correctness and actuality of this knowledge (Van der Hulst, 1999). Research on situation awareness in a simulated driving task shows that drivers having more active control of the driving task, focused attention more accurately on potentially hazardous cars, than when they viewed driving from the (passive) passenger seat. This suggests that awareness of the information necessary for succesful driving is better when people have more active control over the driving task (Gugerty, 1997). In general, situation awareness is necessary for drivers in order to decide whether planned actions and manoeuvres can be carried out safely and should therefore not deteriorate when automating the driving task.

3.4.3 Implications for driver support systems

In the light of these driving behaviour models that stress the importance of mental models, it can be concluded that when driver support systems modify the observable behaviour to such an extent that it does not completely fit the driver's internal models, the prediction based on the existing mental models may fail. While a limited number of road users are equipped with advanced support systems, other drivers will not encounter this modified traffic behaviour enough to adapt their internal model. In a situation of a mixed population of vehicles with and vehicles without intelligent driver support systems, problems with the predictions may arise when determining which driver will display what kind of behaviour. This may lead to an increase in prediction errors and ultimately to more accidents (Heijer, 1997).

According to Stanton & Young (1998), it is likely that drivers will construct mental models of the driver support systems with which they are driving. This will lead them to either make correct or incorrect predictions about the performance of the system. The beliefs and inferences from these mental models will be based upon the design of the system and their experience with it (e.g. if they should reclaim or not). Becker et al. (1994) found that in the course of different manoeuvres with an adaptive cruise control system (ACC), users were able to understand how the system functions and to grasp its functional system limits within a short time. They concluded that the drivers formed a mental model of sensor and controller behaviour and were therefore able to anticipate and avoid critical driving situations.

Automation of a task can reduce situation awareness by placing the operator out-of-the-loop, thereby distancing the operator from the task function (Endsley & Kiris, 1995). In aviation, placing the pilot out of the loop and the consequent reduction of situation awareness, has been reported as a critical pre-crash factor in numerous reports (e.g. Wiener & Curry, 1980; Moray, 1986; Billings, 1991). For the automation of the driving task, these same concerns must now be addressed within the automotive sector. Tests with Adaptive Cruise Control have shown that task automation can lead to reduced activation, and in some cases to reduced situation awareness (Ward, 1996).

3.5 Operational tasks: attention allocation

Operational control in car driving is usually separated into lateral control and longitudinal control. Lateral control refers to keeping the car within the lane boundaries or steering away from objects that block the path of the vehicle. Longitudinal control refers to activities related to the control of speed, such as braking and use of accelerator and clutch (Van Winsum, 1996). Taxonomic models basically describe these lateral and longitudinal tasks, whereas adaptive models are based on the principle that operators adapt their behaviour to the characteristics of the system to be controlled. Thus, driving demands continuous adaptation to a changing environment.

Taxonomic models concern task analyses, which describe all tasks and subtasks at the operational level that the road user has to perform given a specific situation. Task analyses are prone to become extremely extensive and detailed. The best known example of a taxonomic model is the task analysis of the driving task developed by McKnight and Adams (1970). This task analysis specifies the driving task in terms of behaviour requirements. This means that it describes what the driver should do, it is not aimed at understanding driver behaviour or at describing how the driver actually drives.

Adaptive control models assume that continuous attention is being allocated to the operational tasks, resulting in a continuous error correction. The effects on operational performance are perceived via a feedback loop. If driving is self-paced, the driver adjusts his/her behaviour in terms of increasing speed or decreasing headway if operational performance is improved, or by decreasing speed or increasing headway if the performance deteriorates. When driving is forced-paced, the driver may allocate more effort to increase operational performance (Van Winsum, 1996). When operational driving tasks are performed at the skill-based level, the performance is usually open-loop. But even the most routine performance requires some attention or control, either regularly or at intervals, in order to check whether performance is still in accordance with goals, and whether these goals are still appropriate (Hollnagel, 1993). In general, models with respect to driving at the operational level of the driving task have to do with the allocation of attention over the several subtasks of driving, such as lane keeping, car-following, curve negotiation, gap acceptance and overtaking, and the workload associated with driving.

3.5.1 Attention and workload

In models of information processing any task can be seen as the process of the processing of stimuli. This processing can be controlled or automatic, depending on the quantity and type of practice. Automatic processing is characterised as fast, effortless and parallel processing, which develops on the basis of extended consistent practice. It is contrasted with controlled processing, which refers to slow, serial and effortful processing (Shiffrin and Schneider, 1977). Early models of divided attention asserted that humans behave as a single channel with limited capacity for information processing and that they are unable to perform more than one thing at the same time. Tasks will interfere when they both need general attention. The degree to which these tasks interfere is dependent on the level of required controlled processing (Kahneman, 1973). The fact that humans are seemingly able to perform more tasks at the same time and thus divide their attention efficiently (e.g. keeping course while changing gears and maybe even talking at the same time) was explained by covert attention switching between the tasks (Broadbent, 1958, 1982).

Multi-capacity theories argue that human information processing depends on separate resources and that humans can divide their attention efficiently between concurrent tasks in cases where the tasks draw on separate rather than common processing resources. The most influential of these multi-capacity theories is the multiple-resource theory of Wickens (1984). It states that tasks can be executed concurrently when they utilise different modalities of input (e.g. visual versus auditory) and response (manual versus vocal), when they differ in the demands on certain stages of processing (perceptual, central, or motor processes), and when they require different codes of perceptual and central processing (spatial versus verbal codes). The multiple resource theory predicts more interference between tasks if both tasks demand spatial processes or if both tasks demand verbal processing across any stage.

The specification of the amount of information processing capacity that is used for task performance, is labelled workload (De Waard, 1996; Wiethoff, 1997). *Mental workload* also includes how a certain task goal is reached (e.g. the order of actions), and individual differences and restrictions in performance (e.g. in terms of accuracy or speed). Therefore workload depends upon the individual, and because of the interaction between operator and task structure, the same task demands do not result in an equal level of workload for all individuals. Effort is a voluntary mobilisation process of resources. State-related effort is exerted to maintain the operator's state at the cost of performance, while task-related effort is exerted to maintain performance in the case of increased task complexity. It is argued that both processes indicate an increase in mental workload (De Waard, 1996).

Sources of driver workload may be found both inside and outside the vehicle. An overtaking manoeuvre that has to be performed or an important conversation on the car phone will both increase task demands. Since driving is to a very large extent a visual task, demands on visual resources will be highest. When serial driving sub-tasks are executed in rapid succession, they may integrate into one bigger task such as gear changing, and workload could be decreased (Welford, 1988). Verwey (1996) calls this a motor chunk: a consistent sequence of movement patterns that develops with practice, and is independent of the response selection process.

3.5.2 Automation: vigilance and trust

Automation of operator tasks shifts the role of the operator from active to passive monitoring (Scerbo, 1996). It seems that automation is meant to reduce mental workload, but there are several studies that have shown that monitoring of automated systems for malfunctions during prolonged periods of time induce high levels of workload, despite the fact that information processing requirements for these tasks are low (De Waard et al, 1999). Humans are not well suited to monitor sources of information for extended periods of time (Parasuraman, 1986); they are poor "process monitors" (e.g. Molloy & Parasuraman, 1996) and enforced vigilance in the operational environment is found to be very stressful (Hancock & Parasuraman, 1992). Parasuraman et al. (1992) argued that a temporary return to manual operations may act as a counter measure against poor monitoring behaviour induced by automation. Also, driver alertness in general and attention for the driving task per se decreases in monotonous driving conditions such as motorway driving (Brookhuis & De Waard, 1993), leading to a sub-optimal driver's state.

Mahalel & Szternfeld (1986) claimed that the relocation of task functions from the operator to the automating system may reduce processing demands and operator arousal levels. If the introduction of driver support systems is perceived to lead to a decrease in driving task difficulty, it is quite possible that the driver will underestimate the performance demands, leading to reduced arousal levels and a lower level of invested effort. This phenomenon is also described as complacency.

Complacency – overreliance on automation – is one major factor associated with a lack of vigilance in monitoring automation (Endsley, 1996). Complacency has been attributed to the tendency of human operators to place too much trust in automated systems (Danaher, 1980; Wiener, 1985; Parasuraman et al., 1993). Trust in the automated system is a critical factor necessary for it to be used (Lee & Moray, 1992). It is a subjective measure of the degree to which the system can handle a set of situations reliably, safely, dependably, and effectively. Muir & Moray (1996) found a high positive correlation between trust and use of the automation. There was an inverse relationship between trust and monitoring of the automation: the less operators trusted the automation, the more intensely they monitored it and vice versa. Trust was also found to determine intervention behaviour.

3.5.3 Implications for driver support systems

With the introduction of driver support systems, automating or taking over parts of the driving task, drivers are becoming more and more monitors of their driving task than active drivers. This could lead to a decrease in activation and vigilance problems. There is another problem associated with the development of driver support systems. Collision avoidance systems, adaptive cruise control systems, traffic information- and navigation systems, all individually help drivers, but the combined use will result in overload of the information-processing system (Verwey, 1990). Also, driving should not become a bore because almost everything is taken care of automatically and the driver only monitors the system, nor should it be an annoyance since the driver is out of control.

If a driver support system is perceived to reliably fulfil the driver's expectations, then he/she may trust in its correct operation. If too much trust is placed in the system, the driver may become complacent. Complacency may culminate in compensation for the perceived decrease in risk by adjustment of behaviour towards a more risky style of driving. This is an adaptation of behaviour on the strategical level of the driving task, indicating that effects of driver support systems cannot be considered separately on each of the three levels of driver behaviour models. In the next section an attempt is made to integrate important aspects of the models on all three levels with respect to driver behaviour models.

3.6 Integration: hierarchical framework of driver behaviour

3.6.1 Introduction

Each of the models described in the previous sections make predictions about different aspects of the driving task. However, behaviour at each separate level also influences behaviour at the other levels. The decisions a driver makes at the strategical level about for example, route and speed, influence the behaviour at the manoeuvring level. The other way around, decisions made at the manoeuvring level in reaction to momentary circumstances can change the decisions that are made about route and speed. Although largely constrained by the actual situation, manoeuvres such as obstacle avoidance, turning and overtaking must meet the criteria from the general goals set at the strategical level. Conversely these goals may occasionally be adapted to fit the outcome of certain manoeuvres. Decisions made at the manoeuvring level influence behaviour on the operational level by means of feedback, because momentary circumstances demand reactions at the control level of the car. Also the other way around there is a connection from the operations performed at the operational level to the manoeuvring level.

Driver support systems can focus on adjustments of behaviour at all levels, e.g. adjustments of safety margins when car-following during conditions of poor visibility (manoeuvring level), momentary adjustments of steering and acceleration in response to slippery roads (control level), and changes in trip to avoid driving under certain conditions (strategical level) (Ranney, 1994; Kuiken & Heijer, 1995).

In this section an integrated hierarchical framework of driver behaviour (Boer & Hoedemaeker, 1998) is proposed that is structured along the three different driver behaviour levels. Cognitive constructs such as driver needs are connected to the low level operational driving tasks. With the aid of this framework, predictions can be made about how automation of a particular driving subtask may influence the overall driving behaviour and to what degree these may be driver dependent.

3.6.2 Description of the framework

In the proposed hierarchical driver model (Boer & Hoedemaeker, 1998), driving can be characterised as goal directed behaviour; aiming to satisfy the personal needs at the highest level in the hierarchy. This goal directed nature of driving is characterised by a set of higher level needs that affects the way in which the set of observable low level driving tasks is performed. To characterise the means by which drivers arrive at a decision a satisficing decision theory is adopted (see also section 3.3.2). Mental models, evaluating the consequences of committing to a particular alternative, give input to arrive at a satisficing decision between alternative strategies or actions.

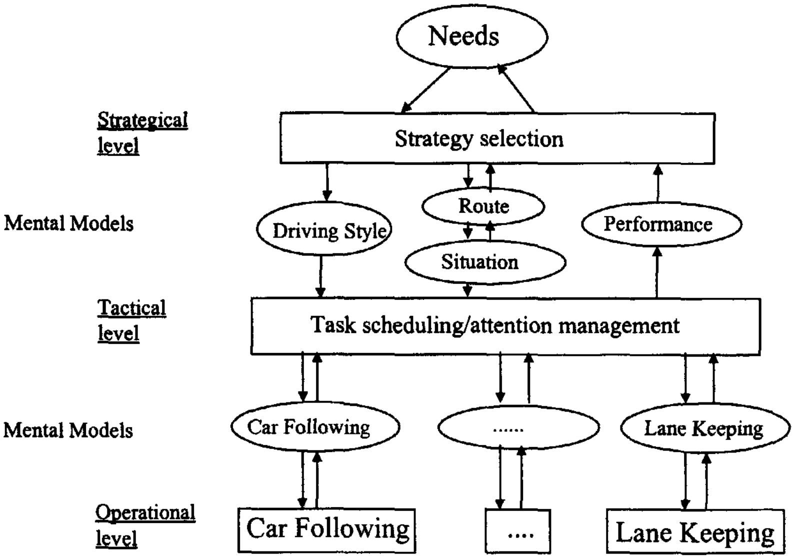

Figure 3-1. Hierarchical Framework of driver behaviour.

The hierarchical framework of driver behaviour, presented in figure 3-1, is composed of the three control levels of driver behaviour (see section 3.2) at which priorities are selected and subtasks from a lower level are co-ordinated based on satisficing decision-making. This co-ordination can be seen as scheduling; the assignment of priorities and resources to perform a collection of tasks (Dessouky et al., 1995). Priority assignment and co-ordination are goal-directed. The levels that co-ordinate and control in the hierarchical framework of driver behaviour may seem to involve a homunculus-like structure, because of their decision-making acting. However, the control levels do not have the role of central supervisory system. They communicate by means of intermediate mental models. Mental models provide information that facilitates the decision process by guiding the perception, prediction, evaluation, and action cycle of performing a particular task.

The information flows through the proposed hierarchical framework as follows:

- At the highest level strategies are selected and need satisfaction is evaluated. At this level it is assessed whether the current choice of trip is satisficing. The performance mental model provides assessments of the degree to which various needs are met. If the current trip is not satisficing, the route mental model is consulted to provide evaluations about the expected consequences of taking alternative routes. The usefulness of these evaluations depends on knowledge about and past experiences with those routes. At this strategical level, a decision is made about which route to take and speed to adopt.
- This choice is communicated to the route mental model, which predicts imminent situations and feeds them to the tactical level for anticipatory attention management and task scheduling. Given the current situation and the set of driving tasks referred to as 'driving style', the task scheduler at the tactical level divides attention and resources over the different low level operational driving tasks. A particular driving style therefore, refers to the way individuals choose to drive based on their higher order needs and takes into account the current traffic situation. It consists of a configuration of low level operational driving behaviour.
- Each operational task has its own mental model that continuously gets input from the state of the driver, the vehicle, the automation, and the environment. It evaluates the consequences of alternative decisions (including the one currently active), predicts future states in response to various alternatives, and communicates this information to the tactical level that uses it to manage attention and schedule relevant tasks.

Strategical level: Needs and strategy selection

The strategical level represents how a driver's particular needs for a given trip are used to determine whether the driver is satisfied with the way the trip progresses. Based on the important aspects in driving that were reported in the literature (e.g. Rothengatter, 1988; Summala, 1988; Rumar, 1993; Forward, 1997; see also previous sections), the following need taxonomy is proposed:

- Safety
- Expediency (driving time, reaching destination as quickly as possible)
- Pleasure (favouring certain routes or roads, enjoying the surroundings)
- Kick of driving
- Workload reduction
- Compliance to social norm (adapt behaviour to that of others and/or traffic laws)
- *Economic cost reduction*

Some of these needs can be seen as global goals to achieve or as benefits (accuracy), whereas others function more as constraining factors or as costs (rejectability). Benefits are composed of safety, expediency, pleasure, and the kick of driving, which characterise a driver's global goals or reasons for getting in the car in the first place. The costs are those criteria that constrain behaviour and include perceived risk, workload, economic cost, and compliance to social norm. They constrain the degree to which these goals can be achieved.

To determine whether a particular strategy is satisficing, the accuracy and rejectability utilities are estimated. If the driver is not satisfied, strategical adaptations are made in terms of changing routes or driving styles (i.e. a relatively stable configuration of driving tasks such as lane changes and overtaking). Once a particular route has been selected, the route mental model guides the task scheduler, via a situation mental model, by providing step by step instructions. The task scheduler in turn updates through the situation mental model, the route mental model each time a particular manoeuvre has been completed.

Tactical level: Attention management and task scheduling

At the tactical level the task scheduler orchestrates which manoeuvres and low level driving tasks (e.g. lane keeping, car following) are performed. The task scheduler communicates performance-related information of the low level driving tasks, via a performance mental model, to the strategical level. The following list, with examples, provides some insight into the types of behaviour related to the seven needs:

- Risk: frequency of switching to a critical event task handler (e.g. obstacle avoidance, lane correction, hard braking); average time headway.
- Expediency: average speed; distance travelled.
- Pleasure: amount of time attention directed to the environment.
- Kick of Driving: percentage of time in which full acceleration, high speed curve negotiation, or fast driving is possible.
- Workload: proportion of attention capacity allocated for task performance; frequency with which tasks are switched.
- Compliance to social norm: frequency of adapting speed to other drivers.
- Economic Cost: time spent in stop and go traffic, city driving, mountains, etc. (compute fuel usage); average speed; distance travelled; how many tickets.

Operational level: Low level task handlers and skill-based controllers

Every single basic operational driving task (e.g. car following, lane keeping, over taking) has its own mental model that guides the perception-action cycle. Monitoring, integration, and evaluation of these subtasks are performed by the task manager. The set of active mental models at the operational level is dependent on the situation, thus, depending on the situation, different mental models ask for different amounts of attentional resources. Switches between mental models can occur when:

1. The situation demands a new manoeuvre to be executed or a new task to be performed.
2. The current manoeuvre, which has been left in open loop mode or unattended for some time, is calling for a control update.
3. Spare attentional resources are available and some task that does not require steering or pedal input can be initiated.

Given that driving can be considered a process of carefully orchestrating an array of tasks, the issue of appropriate attention management and task scheduling is of critical importance. Low level mental models are assumed to communicate their need for attentional resources to the higher-level attention management system. This, in turn, assigns attentional resources based on who needs it most. Each operational mental model is assumed to communicate the following information to the task manager:

1. How many resources are required to perform the task.
2. At what time in the future resources will be needed and for how long.
3. Performance evaluation (to be communicated further on to higher levels).

Changes in the environment are perceived by the low level task mental models and higher level situation mental model. These perceived changes can lead to either (1) small updates within the separate operational tasks, (2) a change in the set of active mental models, or (3) a change in driving strategy, i.e. changing route of driving style.

3.6.3 Interaction with driver support systems

In the hierarchical framework of driver behaviour, the introduction of driver support systems does not significantly alter the above-described structures, it merely introduces an extra mental model associated with the task that the system is capable of supporting or performing. Several interesting issues arise with the introduction of a system that is capable of vehicle control under a limited set of conditions. Most driver support systems do not take over any part of the driving task 100% or under all conditions (see chapter 2). They merely assist the driver in performing a particular task with less effort. In nearly all cases, drivers are still expected to pay attention. For example, Adaptive Cruise Control (ACC) systems, often have limited sensing capabilities and are often not equipped with emergency braking. This requires the driver to identify these emergency braking situations and take precautionary action.

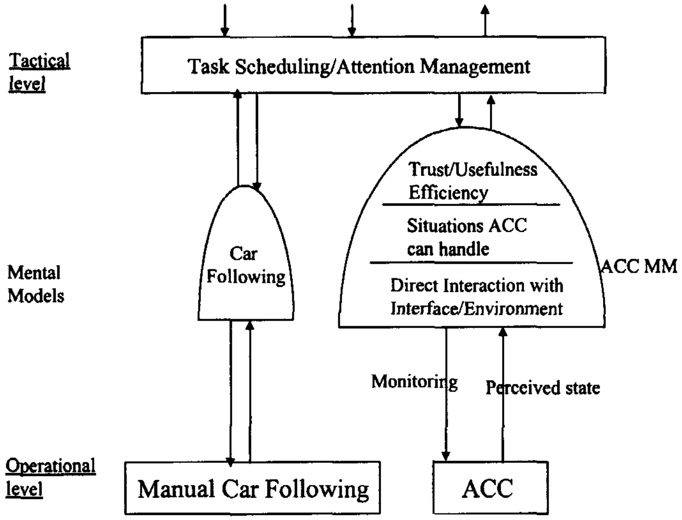

Figure 3-2. Detailed structure of the tactical and operational level when a mental model of ACC is introduced.

Figure 3-2 shows that the insertion of an Adaptive Cruise Control system offers the task scheduler an additional choice, namely whether to use the automation or do it manually. A mental model of ACC has to be initialised via instructions about its interface, its functionality, and its operational limitations. Interaction, exposure, and experience then shape the mental model of ACC through a feedback mechanism in which prediction errors are used to update the various components of the mental model. Some of the important issues in the adaptation process are the level of automation or the degree to which the driver is taken out of the control loop, the new role of the driver, the rate at which semi-critical events (the ones that the ACC cannot handle) develop, and the frequency with which these events tend to occur (Hancock et al., 1996). Ideally, the driver needs to take all these issues into account to arrive at the appropriate safety-conscious role division between driver and system.

If the ACC is capable of performing the car-following task safely and comfortably under all circumstances, then the driver can effectively deactivate the manual car following mental model. However, given the current technological limitations, ACC systems will not be able to perform without human monitoring and intervention. It is important to consider how drivers may obtain and develop a mental model of the ACC and how they may use it. The driver's mental model of the ACC should offer the task manager a realistic assessment of ACC performance as well as an estimate of how long it can be left unmonitored. With a correct mental model of the automation, drivers can effectively assess whether manual control is favoured over automation in a particular context.

Adaptation of the ACC mental model is the result of two processes that operate at different abstraction levels within the mental model (see figure 3-2). The first is based on the degree to which the expected behaviour, as provided by the ACC mental model, differs from the observed behaviour. Depending on the degree of wrong predictions, the ACC mental model is updated to arrive at a more accurate account of the ACC's operational domain. The second process that affects mental model adaptation takes place at a higher abstraction level in the mental model. If it appears that adaptation of the ACC mental model does not reach a stable configuration because of apparent inconsistencies in the system's behaviour, then trust, usefulness, and efficiency attributed to the system may decrease. The result is that drivers may start to rely less on the system and more on manual performance of the driving task. If, on the other hand, the ACC mental model does converge and if the operational constraints are easily tied to a particular situation and conditions, then the driver may start to rely more on the system. Consequently, prediction errors may not be evaluated as frequently to allow for more efficient use of attentional resources.

In this framework trust is defined at a higher level of abstraction in the ACC mental model. The mental model of the ACC is primarily shaped through interaction with the physical system, resulting in a representation of the situations that an ACC can handle. Trust is shaped through evaluations of these levels in the ACC mental model, i.e. the adequacy of the operational mental model of the ACC. Similarly, usefulness, comfort and efficiency are subjective labels based on evaluation of mental model predictions. They are efficient measures in the process of attention management and task scheduling and therefore influence whether using the automation makes the overall driving task satisfying.

3.7 Conclusions and central hypotheses in the thesis

The hierarchical framework of driver behaviour that carries aspects of most of the theoretical models that were discussed in this chapter, illustrates the assumption that a driver's needs are related – via strategy selection and attention management – to the driver tasks at the operational level. An Adaptive Cruise Control system takes over tasks at this operational level. Performance related information is communicated back to the strategical level, where needs represented by global goals (e.g. expediency) and constraining factors (e.g. risk avoidance) determine whether the driver is satisfied with the way the supported driving progresses. If the driver is not satisfied, he/she may change his/her driving strategy, resulting in a change of driving style or chosen route. Changes in the environment that make the situation not suitable for automatic driving, may lead the task scheduler to disable the ACC and devote attention to manual car following.

In this thesis the relationship between individual needs of drivers and the influence of driver support systems on their behaviour is further investigated. The central hypothesis is that if driver support systems are not in line with their needs, drivers may change their strategies, disable the automated systems, or react by changing their operational behaviour.

The higher level needs of drivers and driving styles are explored further in a questionnaire study, within the hierarchical framework. Based on the taxonomy of needs that was proposed in this chapter, hypotheses can be formulated on how these needs influence driving with ACC.

For example, drivers who have safety as an important need will be satisfied with the system if trust in the ACC mental model is high. The task scheduler will allocate the speed and headway keeping tasks to the ACC, when the system has proved to perform these tasks adequately and safely (thereby satisfying their higher level needs). However, this will change their role from an active participant to a passive monitor; their control is taken out of the loop. If these drivers prefer to stay in a closed loop (depending on their trust and perceived usefulness of the system), the task scheduler will allocate resources again to manual speed and headway keeping. Drivers with another need, who favour for example the pleasure of driving, will not mind if they are taken out of the loop in their speed and headway keeping tasks. This will give them the opportunity to direct their attention to other things (e.g. in the surroundings). If the ACC is perceived to lead to a decrease in driving task difficulty, it is possible that the driver will underestimate the performance demands, leading to reduced activation levels and complacency.

The questionnaire study investigates needs and driving styles; the upper two levels of the framework. Driving behaviour, the lowest level of the framework, is further explored in two driving simulator experiments. Hypotheses can be formulated on two different levels. The first is about the relationship between reported driving styles and driving behaviour as performed in the simulator. For example, drivers with a high speed driving style are expected to drive faster, make more overtaking manoeuvres, and keep a shorter headway to the vehicle in front. The second line of hypotheses is about the influence of taking over the longitudinal driving task by an adaptive cruise control system. Drivers have to construct a mental model of the ACC systems they are driving with. Usefulness and comfort are subjective labels based on evaluation of mental model predictions. The outcomes of this evaluation determine whether the ACC makes the overall driving task satisfying, in terms of a driver's higher level needs. It follows that behavioural changes are expected when ACC driving is not in line with the individual needs of drivers. It is expected, for example, that high speed drivers will have lower acceptance of an ACC and, where the system permits it, will overrule the ACC more than low speed drivers will. The reason for this is that an ACC system does not correspond to the needs of the high speed driving drivers. When driving an ACC that cannot be overruled the high speed drivers will have an even lower acceptance because the system is more restrictive.

The research described in this thesis uses the hierarchical framework of driver behaviour as a tool to make predictions about needs, driving styles and driving behaviour reaction to driving with an adaptive cruise control system. Although mental models are important mediators between the continuous evaluation and prediction process of actions and the consequences, they are not, as such, research subjects in this thesis.

4. Research methods

This chapter describes the research instruments that were used in the studies that will be discussed in the chapters 5 - 7. These studies consisted of two main types of research: a questionnaire study and experimental studies in a driving simulator. Both types of research and the instruments that were used are described, and their advantages and disadvantages are discussed.

4.1 Introduction

In this thesis hypotheses of the effects of driver support systems are tested, which are based on the theoretical model of driver behaviour as described in chapter three. This model emphasises different aspects of driving behaviour, from needs to actual driving styles and behaviour, so different measurement instruments have to be used. A questionnaire study is conducted to gain insight into drivers' needs and the relationship with driver support systems judgements and self-reported driving styles. Actual driving behaviour and subjective impressions of this experience are measured in driving simulator experiments. A questionnaire is a useful tool to get an impression of the judgements, needs, and self-reported driving styles of a large group of people. A driving simulator is a valid and reliable instrument to study driving behaviour, as long as the set of cues important to the aspect of driving that is the subject of investigation is available in that simulator. Both instruments are described in the next sections.

4.2 Questionnaire study

Questionnaire studies as a means of self-evaluations of driving motivations and behaviour are a valuable tool in traffic psychological research (Hatakka et al., 1997). It is extremely difficult to get valid information, particularly of driving motivations, without asking the drivers. Moreover, driver groups are easily identified by using self-evaluations, and the connection between self-evaluations and behavioural variables is strong. Hatakka et al. (1997) for example show that drivers with a high level of self-reported risky driving habits have a radically higher number of traffic violations and accidents than drivers with a low level of self-reported risky driving habits.

Social desirability is a factor that obviously has an effect on self-reports. However, there is no evidence showing that social desirability would have a stronger inhibiting or facilitating effect on self-reports than on the behaviour itself. Complying to social norms as such can be considered an important factor in traffic behaviour. Furthermore, the social desirability hardly has any other effect than a reduction of reporting some forms of behaviour. If results are still found, the conclusions are on the safe side (Parker & Manstead, 1996).

In general, it is concluded that questionnaire surveys are a valid approach in studying a driver's needs and driving styles. The next section describes such a questionnaire, the Needs and Driving Styles questionnaire (NDS), which is used in a survey study among Dutch car drivers described in chapter 5.

4.2.1 Needs and Driving Styles (NDS) questionnaire

West et al. (1992) developed a Driving Style Questionnaire (DSQ). The choice of items for inclusion was based on behaviours that had previously been shown to be related to accident involvement or risky driving behaviour, like speed and traffic signal violations. In addition, specific questions about feeling in control when driving were included. Questions were also asked about reactions to advice given during driving, about route planning, and about risk taking on the road. Factor analysis of the items of the DSQ resulted in six dimensions that were interpreted as *Speed* (items about driving fast and exceeding the speed limit), *Calmness* (items about staying calm in dangerous situations and when there is little time to think), *Planning* (consulting a map and planning places to stop and rest before setting out), *Focus* (driving cautiously and ignoring distractions), *Social Resistance* (disliking being given advice about driving) and *Deviance* (jumping the lights and overtaking on the inside).

The self-reported dimension of speed has been shown to correlate quite well with actual driving speed in an observation study made by two independent in-car observers during a mixed motorway and urban test route. West et al. (1992) concluded that the self-reports of driving style are reasonable valid reflections of actual behaviour.

The questionnaire that was used in the survey study described in chapter 5 mainly asks about drivers' Needs and Driving Styles and is therefore referred to as NDS. It consists of three parts:

The first part concerns general data and judgements on driver support systems, the second part concerns differential evaluation of basic needs, and the third part concerns the driving style of the respondent (see appendix A for the whole questionnaire). The last two parts are asked for three different kinds of trips:

- A routine trip of commuter traffic
- Long trips (longer than 150 km, e.g. on holidays).
- Short trips (between 0 and 10 km, e.g. shopping or for social purposes).

Part 1

Part one concerns general demographic questions about sex, age, use of the car, and possession of driver's licence. It also confronts the respondent with four different driver support systems and asks for their judgements. Of each of the systems they could tick boxes, which expressed several positive or negative aspects of the system. The systems are described as follows:

1. An *Obstacle Detection* system. This system warns the driver when encountering a vehicle or obstacle too fast. This warning can be done by visual or auditory signals from the dashboard, encouraging the driver to brake.
2. A *Collision Avoidance* system. This system automatically brakes when the driver encounters another vehicle or obstacle too fast. It can be seen as a more automated form of the obstacle detection system.

3. An *Autonomous Intelligent, or Adaptive, Cruise Control.* This system keeps the car at a fixed speed and distance from vehicles in front. If the vehicle in front drives slower or brakes suddenly, the system will automatically lower its speed and keep the car at a safe following distance.
4. The *Automated Highway* is a separate lane on the motorway where automatic cars drive with very small headways in a platoon. Driving on this separate lane is completely automatic. The only thing the driver has to do is get on and off this lane.

Part 2

In the evaluation of different needs, the *stated preference* method was used (van der Heijden & Timmermans, 1988), in which respondents have to rank the importance of different alternatives. The method confronts drivers with alternatives that have to be ranked according to their preferences. The method has the possible disadvantage of excluding some relevant needs, simply because they are not asked for. To compensate for this disadvantage, the needs that were used in this questionnaire were based on a literature study (see chapter 3) and an existing questionnaire (van der Heiden & Rooijers, 1994), in which every item had to be scored on an importance scale ranging from 1 to 5. In our questionnaire, respondents have to rank the needs on a scale ranging from 1 (very important) to 7 (very unimportant). These needs were the following:

- Safety
- Expediency
- Driving relaxed
- The 'kick' of driving
- Driving at own determined speed
- Doing other things while driving
- Enjoying the surroundings while driving

Note that some of these needs are formulated differently than the need taxonomy on which they were based (described in section 3.6.2). 'Workload', for example, is changed into 'driving relaxed', and 'pleasure' into 'enjoying the surroundings'. This was done because it was expected that respondents were better able to imagine what they think is important during driving with these more appealing formulations. Economic cost is not included in the questionnaire because it was added to the need taxonomy after the questionnaire study.

Part 3

This part concerning driving styles is based on the Driving Style Questionnaire (DSQ), which was described above (West et al., 1992). Of the six factors distinguished in the DSQ, the factors Social Resistance and Planning are excluded in the NDS questionnaire because they measure driving styles on a more strategical level. This strategical level of driving is in the NDS questionnaire covered by part two; drivers' needs or higher level goals. As is explained in the hierarchical framework of driver behaviour (see chapter 3), needs at the strategical level are linked to driving styles at the tactical level of driving behaviour.

The result was a 17-item list, phrased as questions asking about frequency of a given type of behaviour. Respondents were instructed to tick one of five boxes that indicated how often they behaved in this way: almost never, seldom, sometimes, often, or almost always.

A principal component analysis and a varimax rotation were performed on the 17 driving style questions. They revealed five components accounting for 55.8 % of the variance (Q-q plots and histograms revealed that the data are approximately normally distributed), which are interpreted as Speed (made up of items about driving fast and exceeding the speed limit), Deviance (jumping the lights and overtaking on the inside), Carefulness (driving cautiously and adjusting speed to others), Lane-change behaviour (changing lanes often) and Focus (ignoring distractions). Separate analyses were carried out on two randomly selected sub-samples each comprising half of the full sample. The resulting loadings were similar in the two sub-samples and both were similar to the results of the analysis on the full sample, indicating a stable structure. Table 1 shows the dimensions, the percentage of variance that they accounted for, the alpha reliability coefficient, and the item loadings.

Table 4-1: Item loadings on the dimensions of Driving Style.

Scale	Factor Loading	Item
Speed	.77	Do you drive fast?
(24.4% of variance)	.74	Do you exceed speed limits in built up areas?
	.77	Do you exceed speed limits on rural roads?
Alpha=0,81	.52	Do you exceed speed limits on highways?
	.78	Do you become flustered...?
Deviance	.72	Do you ever drive through a red light...?
(9.5% of variance)	.65	Do you take right of way......?
Alpha=0,55	.65	Do you overtake on the inside....?
Carefulness	.77	Do you adjust your speed ....?
(7.2% of variance)	.65	Do you keep a large headway .....?
Alpha=0,53	.56	Do you drive cautiously?
Lane-change	-.82	Do you drive on the same lane....?
(8.1% of variance)	.82	Do you change lanes often?
Alpha=0,56	.39	Do you filter in shortly...?
Focus	.58	Do you find it easy to ignore distractions....?
(6.6% of variance)	-.70	Do you respond to pressure from other drivers?
Alpha=0,39	.61	Do you ignore passengers urging you to…?

The reliability coefficients alpha can be called acceptably high. The factor-scales do not completely correspond to what West et al. (1992) found, but are quite similar. Questions as "Do you become flustered..." and " Do you respond to pressure from other drivers..." are interpreted by West et al. on a scale called Calmness, whereas in this questionnaire they load respectively on the scales Speed and Focus. The items loading on the Lane-change and Carefulness scale were not part of the original questionnaire by West et al., except for the item "do you drive cautiously", and form therefore new factor-scales.

4.3 Driving simulator experiments

The experimental studies were aimed at studying the effects of different forms of Adaptive Cruise Control systems on driving behaviour and acceptance. In the driving simulator at the Centre for Environmental and Traffic Psychology (Van Wolffelaar & Van Winsum, 1992), participants could actually drive with these systems and so driving behaviour, activation and effort during the experience were measured, as well as acceptance and subjective effort after experience. The instruments that were involved in these experiments are described in this section.

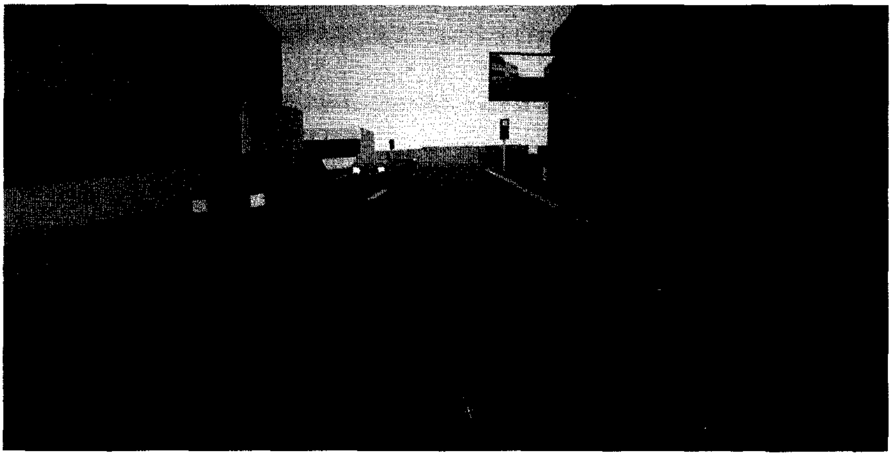

Figure 4-1. Picture of the driving simulator of the Centre for Environmental and Traffic Psychology.

4.3.1 The driving simulator

The driving simulator at the Centre for Environmental and Traffic Psychology (COV) of the University of Groningen has been developed to provide a safe and controllable environment for road user studies. It allows the driver to move freely in a network of roads with signs, buildings, and road traffic as if driving in the real world. The events a driver will encounter can be programmed by means of 'scenarios' that generate predetermined traffic situations.

The driving simulator consists of a car cabin, which is a modified BMW 518 with all the original controls like steering wheel, accelerator, brake and clutch pedals, switches, dashboard indicators and a manual gear shift that can be switched to automatic. The screen image is generated on a Silicon Graphics Onyx RE2 computer and projected on a large graphical projection screen showing the road environment from the perspective of the driver with a horizontal angle of about 165 degrees. Images were presented at a rate of 15 to 20 frames per second.
In figure 4-2 a functional overview of the driving simulator is given.

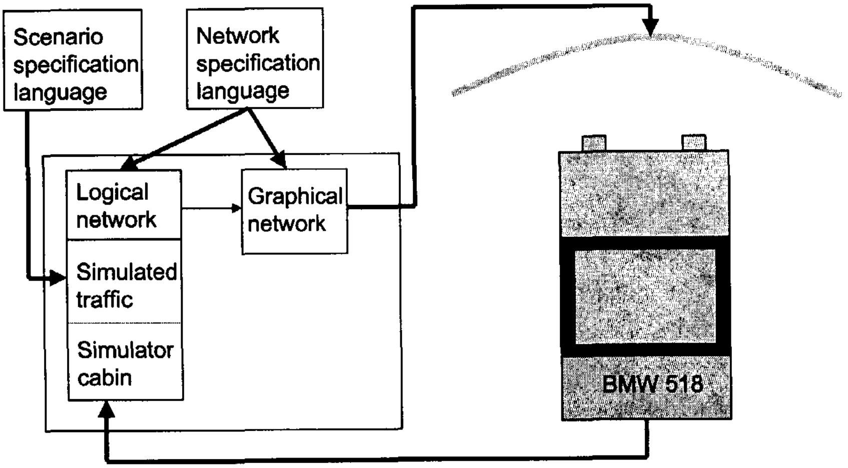

Figure 4-2. Functional overview of the driving simulator at the Centre for Environmental and Traffic Psychology.

The virtual world, presented at the screen, consists of a simulated interactive traffic environment with on the one hand a **logical road network** (roads, signs, buildings from the **graphical network**) and on the other hand the dynamic scene (cars, traffic lights from the **simulated traffic**). The definition of a new task environment starts by defining the logical road network with the aid of **network specification language**.

Next a **scenario specification language** defines interactive traffic participants and their individual actions within this specified road environment. The simulated cars move autonomously through the perceived environment while attempting to establish their individual goals. They do this by evaluating a set of behavioural rules that lead to appropriate manoeuvring decisions and corresponding actions for which a descriptive model of human driving is used, presented in detail in Van Winsum (1991). These vehicles that consider this car as just another participant perceive the movements of the simulator cabin, which is controlled by the simulator driver. The cars interact with each other and with the simulator car in which the subject is seated (Van Wolffelaar & Van Winsum, 1992). Despite their primitive appearance, the cars are perceived as realistic traffic participants due to their natural interactive behaviour. However, since the simulator is fixed-base, the driver lacks the locomotion sensations experienced in real driving. For some drivers this discrepancy between visual movements and locomotion standstill can lead to nausea or ‘simulator sickness’.

4.3.2 Simulator driving and driving in the real world: validation issues

There are many reasons to use driving simulators in research concerned with traffic behaviour. According to Nilsson (1993) an important advantage of simulators is that they allow driving conditions and environmental conditions to be kept constant. All subjects participating in a study can be exposed to exactly the same conditions. In field experiments, it is obvious that the factors that influence driver behaviour (except those studied) are usually too many and too unpredictable to be appropriately controlled. Moreover, interactions between the factors can make the interpretation of results from field studies very difficult. Therefore, driving simulators are well suited for comparative effect studies where one or a couple of factors are systematically varied, while all other factors are kept constant. Because the environmental and driving conditions can be kept constant in a simulator, the required number of subjects can be much smaller, compared to field studies without losing statistical power. Also, data collection in experimental situations is greatly facilitated by the simulator since all relevant performance measures are continuously available (Van Winsum & Van Wolffelaar, 1993). Another advantage of driving simulators is that driver behaviour can be tested to the point of catastrophic failure. No matter how seriously degraded the driver performance is (by mental overload, fatigue, drugs, alcohol etc.), there is no danger to the driver or other road users. In the light of the modern information technology to support drivers in their task, another advantage with simulators is obvious. Namely that it is possible to test and evaluate proposed in-vehicle systems during the conceptual phase of the development (Nilsson, 1993).

Simulator studies have many advantages, but it will never be the same as real driving. A problem with most driving simulators is that drivers experience a lack of correspondence between visual and motion information, which can lead to uncertainty and abnormal behaviour. These limitations are most likely to appear in experiments that contain many sharp bends and that require fast manoeuvres (Nilsson, 1993).

Validity tests are required in order to prove that driving behaviour in simulators is realistic. Validity tests involve the comparison of driving behaviour in a simulator with driving behaviour in an instrumented vehicle or observed behaviour. For simulator driving absolute and relative validity are distinguished. Absolute validity refers to the numerical correspondence between behaviour data in the driving simulator and in the real situation, whereas relative validity refers to the direction or relative size of the effects of the measure in relation to effects in the real situation. For a driving simulator to be useful as a research tool it is necessary that relative validity is satisfactory, that is at least similar effects are obtained in both situations. Absolute validity is not a necessary requirement, since research questions almost uniquely deal with matters relating to effects of various independent variables (Törnros et al., 1997).

Kaptein et al. (1996), in a survey of several validation studies, showed that there are limitations in the validity of a fixed-base driving simulator in assessing driving behaviour. The results generally had relative validity, but no absolute validity. For example, Tenkink (1989, 1990) showed in a number of studies that in the driving simulator subjects generally drove at higher speeds, combined with a larger standard deviation of lateral position (sdlp), but the experimental effects were in the same direction as driving on the real road. The differences in absolute level of driving speed and sdlp were related to the lack of proprioceptive information and the small amount of visual information. Godley et al. (1997) carried out two experiments to validate their fixed-base driving simulator. Speed and braking actions were found to be highly correlated between the on-road and simulator experiments. Deceleration, however, did not result in a strong validation, which, they concluded, may be due to the lack of horizontal motion cues associated with real-life braking but lacking in the simulator. De Waard & Brookhuis (1997) found that the amount of effort subjects put into driving in a simulator, as measured by the RSME (Rating Scale Mental Effort, see further on in this section), is much higher compared to driving in a real car.

The general conclusion may be drawn that a driving simulator is a valid instrument to study driving behaviour, as long as the set of cues important to the investigated aspect of driving, is available in that simulator. On top of this, it should be kept in mind that it is only meaningful to draw conclusions on the relative size of effects.

4.4 Subjective measures

Rating scales are frequently used to assess the subjective appraisal of a test condition. Rating scale techniques limit or restrict the individual's responses because options for response tend to be fewer and focus much more on specific aspects of interest. Using a rating scale also means a quick and standardised way to assess the participant's appraisal in a number of situations and answers are easily processed and analysed afterwards (Jesserun, 1997). This section describes the rating scales that the participants of the driving simulator experiments, had to fill out after each condition.

4.4.1 Acceptance

A standardised checklist of acceptance of new technological equipment (Van der Laan et al., 1997) is used to measure the participant's acceptance of the systems they experienced in the driving simulator. The checklist is simple and consists of nine 5-point rating-scale items, ranging from -2 to 2. Factor analysis of these items results in two factors. The first factor contains evaluations in terms of useful, good, effective, assisting and raising alertness, and is interpreted as denoting the usefulness of a system. The second factor contains evaluations in terms of pleasant, nice, likeable and desirable, and is interpreted as reflecting comfort associated with a system. The technique has been applied in different studies in different test environments (i.e. driving simulator and instrumented car on the road), showing that the usefulness and comfort scales had a very high rate of consistency in all studies. Rothengatter & Heino (1994) reported a simulator study with three types of Adaptive Cruise control (ACC). The first type of ACC only gave information about the distance to a car in front. The second type had an active gas pedal giving a counter force depending on the distance to a car in front (haptic feedback), and in the third type of ACC speed and distance were controlled autonomously. It was found that all systems were evaluated positively in terms of usefulness, with the autonomous ACC receiving the lowest score. The haptic feedback ACC had the lowest comfort score. In a simulator and field evaluation of different Collision Avoidance Systems (CAS), Janssen et al. (1993) found that the haptic feedback CAS was most consistently positively appreciated in terms of comfort. This was true for both the simulator and the field study. In terms of usefulness there was not much differentiation between the different systems. De Waard et al. (1999) found acceptance ratings of an Automated Highway System comparable to the ones found for the autonomous ACC, i.e. relatively low scores on usefulness and comfort probably due to take-over of control. In general it can be concluded that the checklist is a reliable instrument for the assessment of acceptance of new technology (Van der Laan, 1998). An example is shown in appendix B.

4.4.2 Mental effort

The Rating Scale Mental Effort (RSME, Zijlstra & Van Doorn, 1985; Zijlstra, 1993) is used to measure the subjectively experienced mental effort. It is a one-dimensional scale, represented by a vertical line of 15 cm with a number of verbal labels printed at the side (completely undemanding to tremendously demanding). Subjects are asked to give a mark at the point that represents their experienced effort investment. De Waard (1996) found in a number of driving studies that the RSME was sensitive to added workload on top of the driving task in the case of use of a car phone, and in tutoring conditions (i.e. feedback on driving behaviour). He also found that the RSME is sensitive to state-related effort (exerted to maintain the driver's psycho-physiological state). Veltman & Verwey (1996) found that the RSME was affected by loading and task duration, and also showed an interaction in a study in which car driving was combined with secondary tasks. According to Wiethoff (1997) the RSME is a valid, reliable, and easy to use scale for laboratory and field studies. Because of its quick application, it can be filled out between tasks, even if these tasks only last a few minutes. However, caution is needed, because individuals can consciously manipulate their scores. Appendix C shows an example of the RSME.

4.4.3 Activation

The Bartenwerfer activation scale (Bartenwerfer, 1969) is used to measure the subjectively experienced activation. As with the RSME, it is a one-dimensional scale, represented by a vertical line of 27 cm with a number of verbal labels printed at the side ('deep sleep' to 'frightened to death'). Subjects are asked to give a mark at the point that represents their experienced activation during the last experimental condition. The scale is validated for driving research in a number of studies. Louwerens et al. (1986) reported a study in which the effects of several antidepressants on driving behaviour and subjective mental activation were measured. They concluded that the subjective results parallel the objectively measured differences in driving behaviour to a large extent. On the basis of studies reported by De Waard (1996), he concludes that the scale is fit to be used for effects on subjectively experienced effects on the Central Nervous System. In a simulator study on an Automated Highway System (AHS) (De Waard et al., 1999), the Bartenwerfer scale proved to be sensitive to perceived activation for AHS conditions with varying time headways. The scale is also very easy to use and very quick in its application. However, the scale is comparable to the RSME, and sometimes similar effects on both scales were found, so it might be argued that it may be difficult for subjects to discriminate between perceived effort and perceived activation during a particular task. The Bartenwerfer activation scale is shown in appendix D.

In general, subjective techniques have several advantages and disadvantages. Advantages are that these techniques are globally sensitive indices of workload and activation, they typically require little instrumentation, and the user acceptance is high. A disadvantage is that the subjective appraisal of, for instance, the level of workload, can be influenced by factors other than the actual level of load experienced by the driver, such as contextual effects (Wierwille & Eggemeier, 1993).

4.5 Physiological measures

Over the past few decades characteristics of the rhythm of the cardiovascular system has been used widely to measure psychophysiological state and mental effort both in laboratory and field studies (Wiethoff, 1997). In this section measures of heart rate and heart rate variability are discussed because these measures are used in the last simulator experiment, described in chapter 7.

4.5.1 Heart Rate

The autonomous nervous system controls internal organs and is autonomous in the sense that the innervated muscles are not under voluntary control. The heart is influenced by the autonomic nervous system, and through this connection related to physical and emotional states as well as to cognitive activities (Wiethoff, 1997). Heart rate is known to be related to the amount of physical activity, respiration, thermal regulation, and muscle preparation for movement (Lysaght et al., 1989). Kalsbeek & Ettema (1963) found that fluctuations in the interbeat interval (IBI, the time between two peaks in the electrocardiogram) were reduced during mental task performance. De Waard (1996) found that driving compared to rest measurements significantly elevates average heart rate. Compared to baseline measurement (during driving) he found that driving through a weaving section and using the car phone resulted in an increase of average heart rate. Time-on-task or vigilance on the other hand resulted in a decrease of average heart rate. Fairclough et al. (1991) found that average heart rate was higher while performing a secondary task presented through a hands-free phone, compared with the same task presented by an experimenter in the passenger seat. The authors give two possible explanations for the effect, either additional effort is required in the phone condition due to lack of conversation, or unfamiliarity with cellular phones activated the subjects.

With the use of heart rate profiles it is possible to monitor heart rate at a more continuous level. De Waard (1996) used a window of 30 s, moving it over the heart rate pattern with steps of 10 s, resulting in a smoother heart rate profile. He found differences in heart rate linked to specific road segments where subjects were driving. Driving over dual carriageways clearly reduced heart rate, and driving around roundabouts increased heart rate. De Waard et al. (1999) found with the profile technique a clear heart rate decrease when drivers experienced an emergency situation on the automated highway. This decrease is explained as a surprise reaction to a novel situation.

4.5.2 Heart Rate Variability

Heart rate variability (HRV) is less under the influence of physical movement than heart rate and more sensitive to mental effort. Three frequency bands of the HRV have been identified (Mulder & Mulder, 1981): A *low frequency* band (0.02-0.06 Hz) related to the regulation of body temperature, a *mid frequency* band (0.07-0.14 Hz) related to short term blood pressure regulation, and a *high frequency* band (0.15-0.50 Hz) related to respiration. Numerous studies have found evidence that mental effort investment suppresses HRV (e.g. Mulder, 1980; Mulder & Mulder, 1981; Aasman et al., 1987; Vicente et al., 1987), especially in the mid frequency band, which is also called the 0.10 Hz component. In driving for example, Van Winsum et al. (1989) found navigation based on a map to be more effortful than navigation by vocal messages, as measured by a decrease of the 0.10 Hz component. Janssen et al. (1994) did not find significant effects on the 0.10 Hz component in an on-the-road study where drivers received support in the form of warning and tutoring messages. De Waard (1996) found that HRV profiles provide a reliable reflection of mental effort associated with different tasks. Waiting for a traffic light coincides with increases in variability, while driving on a roundabout corresponds to decreases in HRV. Wiethoff (1997) used the same HRV-profile technique in a word-processor task. The results showed that interaction with the interface coincided more with HRV suppression, especially in what she calls 'struggling' task behaviour. She concludes that HRV-profiles are a useful tool in detecting changes in heart rate variability over a shorter period of time. More importantly, they help distinguish between controlled and automatic processing.

The general conclusion may be drawn that heart rate provides an index of overall workload or activation, whereas heart rate variability is more useful as an index of cognitive, mental workload (Wilson & Eggemeier, 1991). Profiles of heart rate and heart rate variability may be helpful in linking changes in the pattern to specific events in the driving environment.

5. Needs and Driving Styles

This chapter describes a questionnaire study among Dutch car drivers about their judgements of different driver support systems and their needs and driving styles during different kinds of trips. All three aspects (judgements, needs and driving styles) are considered important for the future developments of driver support systems.
The results of the questionnaire show that the respondents see both positive and negative aspects to the four driver support systems. About 50% of the respondents indicates that traffic safety will increase when driver support systems are introduced. Respondents were negative about having taken over control of driving by a system. As was predicted from hierarchical framework of driver behaviour, the results show a relationship between needs and some of the self reported driving styles. Needs and driving styles can be seen as stable traits that can be different between drivers but not very much between trips. That is, drivers don't change their needs and accompanying driving styles when going on different trips like commuter or holiday trips. This conclusion is used in the experimental studies described in the following chapters. An important selection criterion for the subjects participating in the experiments was their self-reported driving style. This gives the opportunity to predict their behaviour and reactions to driving with driver support systems, because we can expect this to be in line with their higher level needs.

5.1 Introduction

5.1.1 Needs and driving styles

Over the years, researchers working with traffic safety have been looking for stable or relatively stable individual factors related to driving behaviour, since drivers' choices in traffic may reflect their attitudes and beliefs about car driving (Ranney, 1994; Lajunen & Summala, 1997). Based on a questionnaire study, Steg et al. (1998) found that motives for car use are threefold: instrumental motives, social motives, and affective motives. The instrumental motives refer to the more or less objective consequences of car use, such as speed, flexibility, safety and environmental problems resulting from car use. Social motives refer to the fact that people can express themselves by using a car and people can compare themselves with others. Affective motives refer to various emotions that are evoked by using a car, that is, driving may potentially alter people's mood. These emotions are mostly based on a combination of a degree of pleasure and arousal.

These types of motives correspond to the higher level needs of drivers that were proposed to play an important role in driving style and driving behaviour in chapter 3. The hierarchical framework of driver behaviour shows that a drivers' needs (at the highest, strategical level) are related – via strategy selection and attention management – to the driver tasks at the operational level.

Needs are defined as the higher level goals that drivers try to satisfy. According to Rumar (1993), the motives and the goals for travelling are the basis for the needs. The primary goal for drivers is of course to reach the destination, but they do not accept that goal at any price. They aim to achieve their goals to a high degree of satisfaction without violating constraints too much. The driver requires a certain time, speed, safety, economy and comfort. These are needs that drivers try to satisfy. This is not always possible because of the current traffic situation. Needs are therefore translated into local goals that are congruent with the situation at hand, expressed in different driving styles. If, for example, expediency is a driver's most important need, then this can be translated into driving fast with many hazardous lane changes or taking a different route with less traffic that allows for higher but illegal speeds. Based on a literature survey chapter 3 proposes the following taxonomy of needs (Boer & Hoedemaeker, 1998):

- Safety
- Expediency (driving time, reaching destination as quickly as possible)
- Pleasure (favouring certain routes or roads, enjoying the surroundings)
- Kick of driving
- Workload reduction
- Compliance to social norm (adapt behaviour to that of others and/or traffic laws)
- Economic cost reduction

Driving style concerns the way that individuals choose to drive. It refers to choice of driving speed, threshold for overtaking, preferred headway and tendency to commit traffic violations. It may be expected to be influenced by needs, values and beliefs relating to driving (West et al., 1992). West et al. (1992) developed a driving style questionnaire and reported a correlation of .65 between observed driving speed and responses on the driving speed subscale of their Driving Style Questionnaire. They concluded that self-reports are reasonably valid reflections of actual behaviour (see also chapter 4).

In the proposed hierarchical framework of driver behaviour, driver support systems can be placed at the lowest operational level, where they actually take over some of the driving tasks. Performance related information is communicated back to the strategical level, where needs represented by global goals (e.g. expediency) and constraining factors (e.g. risk avoidance) determine whether the driver is satisfied with the way the supported driving progresses. In other words, needs determine a driver's acceptance of driver support systems.

5.1.2 Acceptance of and attitudes towards driver support systems

The degree of acceptance of driver support systems (i.e. drivers like these systems and become familiar with it) is assumed to be influenced by the effectiveness of these systems. An important requirement for the introduction of in-vehicle technology is the acceptance by the public, because "it is unproductive to invest effort in designing an intelligent system if the system is never switched on, or even disabled" (Van der Laan, 1998). But it is not an easy task to investigate acceptability, especially through attitude measurement, a priori and before the physical and functional demonstration of the system in practice, i.e. in a driving simulator or in real traffic situations (Brookhuis & Soeteman, 1998a). Attitude refers to the evaluations of the consequences of performing a specific behaviour. It is important because it reflects an intention to certain behaviour (see also chapter 3.2 for Fishbein & Ajzen's attitude paradigm (1975)). Attitude is not a directly perceptible object and can be approached only in a mediated manner through various indicators: opinion scales, attitude questionnaires, etc.

Steele (1995) points out that consumers are the driving force in the economy, and that their acceptance of driver support systems will determine its degree of success. According to Ortt (1998), knowledge of the needs of potential consumers is a prerequisite for a consumer-oriented product development process. In the innovation phase (with the invention of a technology), consumer research has to focus on the needs of potential consumers and establishes whether or not these needs can possibly be fulfilled by the technology. In his dissertation, he applies consumer research to assess the market potential of video-telephony. He concludes that *communicability* and *compatibility* are the most important attributes in explaining the needs and demands for an innovation. Communicability refers to the degree to which the results of an innovation are clearly apparent, can be communicated to others, and will be positively evaluated by others. Compatibility refers to the degree to which an innovation is perceived as being consistent with existing values, habits, and past experiences of the consumer.

Davis et al. (1989) developed the Technology Acceptance Model (TAM) that specifies the causal relationships between system design features, perceived usefulness, perceived ease of use, attitude toward using, and actual usage behaviour of new information systems. It is based on principles adopted from Fishbein and Ajzen's (1975) attitude paradigm. Their most striking finding was that perceived usefulness was 50% more influential than ease of use in determining usage of new information systems. They conclude that the TAM provides an informative representation of the mechanisms by which design choices influence user acceptance, and should therefore be helpful in applied contexts for forecasting and evaluating user acceptance of information technology (Davis, 1993).

In the field of acceptance of driver support systems, Cairney (1996) conducted a study, in which he showed participants a video outlining the technical basis of the systems and explaining the benefits likely to be delivered. It was found that a vehicle monitoring system was liked the most and that the ACC (Adaptive Cruise Control) was liked the least by participants. While it was acknowledged that the cruise controls made for safer driving and reduced the risk of fines, many respondents could not accept that ACC offered any advantages over conventional cruise control. Many felt that other vehicles cutting in to the gap which the ACC maintained from the vehicle in front would make the system unworkable. Many respondents indicated they disliked the idea of having control taken away from them, and many thought that the ACC would reduce the drivers alertness and capacity to deal with emergency situations.

5.1.3 Aim of the questionnaire study

Drivers' needs and driving styles and the judgements on driver support systems are the subject of a questionnaire study, presented in the next method section. As is argued above, all three aspects are important in the study of driver support systems. According to the hierarchical framework of driver behaviour, needs and driving styles are important, because whenever driver support systems frustrate a driver's needs, they may disable the automated systems or react in other undesirable or dangerous ways. When more insight is gained into the needs and how they relate to driving styles, better predictions can be made about drivers' reactions to driver support systems.

The aim of this questionnaire study is twofold. In the first place hypotheses are tested on the relation between needs, driving styles and judgements. Secondly it is used to see if these questionnaire measures of needs and driving styles can be used as a way to form meaningful groups of drivers.

Based on the hierarchical framework of driver behaviour, the following hypotheses are formulated for this questionnaire study:

1. Because needs are the higher level goals that drivers try to satisfy during driving, it is expected that drivers' judgements of driver support systems are related to their needs. More specifically, when certain features of driver support systems appeal to their needs, drivers are expected to have a higher acceptance of that system.
2. Driving styles differ between types of trips because they can be adjusted to satisfy a driver's needs. Needs are a stable factor within a (group of) driver(s). According to the demands they place on the driving task, three types of trips were used in this study: a routine trip of commuter traffic, a long trip (e.g. holidays) and a short trip (e.g. shopping or local social events).
3. A driver's needs for a given trip (in terms of safety, expediency, pleasure, kick, or workload) are related to driving style (in terms of speed, focus, carefulness, and deviant behaviour).

5.2 Method

5.2.1 Structure of the NDS questionnaire

The Needs and Driving Style (NDS) questionnaire that is used in this study is described in more detail in chapter 4. It consists of three parts:

- The first part concerns some general data and judgements on four driver support systems: Obstacle Detection, Collision Avoidance, Adaptive Cruise Control, and the Automated Highway.
- The second part concerns the ranking of seven basic needs; Safety, Expediency, Enjoying the surroundings, Kick of driving, Driving relaxed, Driving at your own speed, and doing other things while driving.
- The third part concerns the driving style of the respondent and was based on the above-described Driving Style Questionnaire. The "adjusted DSQ" resulted in five dimensions that were interpreted as Speed (made up of items about driving fast and exceeding the speed limit), Deviance (jumping the lights and overtaking on the inside), Carefulness (driving cautiously and adjusting speed to others), Lane-change behaviour (changing lanes often) and Focus (ignoring distractions).

In the two last parts three different trips are distinguished to test hypothesis 3; driving styles differ between types of trips and needs are a stable factor within a (group of) drivers. The three destinations are:

- A routine trip of commuter traffic
- Long trips (longer than 150 km, e.g. on holidays).
- Short trips (between 0 and 10 km, e.g. shopping or local social purposes).

5.2.2 Procedure

Sample characteristics

The questionnaire was sent to a sample of 1000 Dutch car drivers, all members of the Dutch automobile association (ANWB) which has more than 3 million members. The sample had the following characteristics:

- They all owned a car.
- Half of them were male, half were female.
- Stratified by age group: 25-34 years, 35-44 years, 45-54 years, and 55-65 years.

Statistical design

The Spearman rank correlation is used to describe the relationship between needs and driving styles, because part two of the questionnaire consists of a rating scale driver needs, which results in an ordinal scale instead of a numerical scale. In the Spearman rank correlation the correlation is based on the rank order of the data instead of on the data itself. In order to test the difference between two paired samples (need ratings on different kinds of trips) the non-parametric Wilcoxon Signed Ranks Test is used. This method tests the hypothesis that the medians, rather than the means, are equal.
Analysis of Variance (ANOVA) for within subjects is used to test the differences on driving style between the trips (Trip with three levels).

5.3 Results

5.3.1 Response and general data

Response rate was 49% (495 out of 1000), with 60% men and 40% women responding. The distribution over the four age categories was almost equal (respectively 25%, 23%, 26%, and 26%). At the moment of filling out the questionnaire the respondents owned their drivers licence for 23 years on average. The average number of kilometres driven a week is 365 (18.980 per year).
In general it can be concluded that the response rate of the questionnaire is reasonably high, and is a good sample of the Dutch driving population where 67% men and 54% women own their drivers licence. 76% of all Dutch households own one car or more and the average number of kilometres driven a year is 16.550 (Centraal bureau voor de Statistiek, 1999).

5.3.2 Judgements on driver support systems

Respondents attributed both positive and negative aspects to the four different systems. About 50 percent thinks that traffic safety will increase when an obstacle-detection-, an anti-collision- or an adaptive cruise control system will be introduced in our cars. A very small percentage of the respondents thinks that traffic safety will decrease (5-10%) as a result of driver support systems. However, also more than half of the respondents are of the opinion that the car will brake at dangerous moments (50-70%). The complete list with the results on all answering categories is shown in appendix E. It should be noted that when the appendix mentions for example that 60% of the respondents reports that traffic safety will increase when introducing an obstacle detection system, it doesn't automatically mean that 40 % of the respondents thinks that traffic safety will decrease. Respondents were free to tick more than one of the positive and negative aspects of the system and were therefore not forced to express their opinion on traffic safety changes.

5.3.3 Reported needs

Figure 5-1 provides an overview of the results concerning the ranked values of the different needs. Along the y-axis the seven needs are shown of which the respondents had to rank the subjective importance from 1 (the most important) to 7 (the least important). These scores are grouped together and called *important* (scores 1 and 2), *in between* (scores 3, 4, an 5), and *unimportant* (scores 6 and 7).

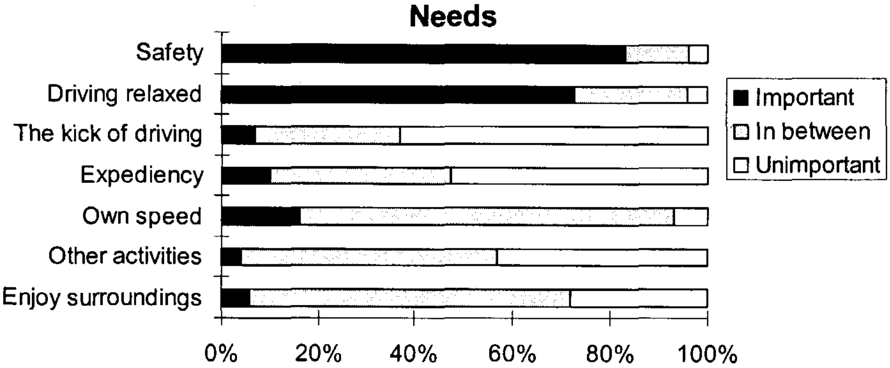

Figure 5-1: Percentages of respondents that consider each of the 7 needs important, half important, or unimportant.

In the first four needs, an 'extreme' opinion can be seen. Safety and driving relaxed are considered important by the majority of the respondents. The kick of driving and expediency are considered unimportant by the majority of the respondents. Being able to drive at your own speed, being able to do other activities and enjoying the surroundings while driving, are considered half-important by the majority of the respondents.

In figure 5-1 the averaged values over the three trips are shown. Tests with the Wilcoxon Signed Ranks Test show that there are no significant differences between most of the needs on the three different trips. Only enjoying the surroundings turns out to be more important on long trips than on short - (Z=-2.1,p<0.04) and commuter (Z=-3.1,p<0.002) trips, and being able to drive at your own speed is judged more important on long trips than on short trips (Z=-2,2,p<0.03).

5.3.4 Reported driving styles

Figure 5-2 shows the differences in reported driving style for the three trips. On the y-axis the average score of the 5 dimensions on the x-axis is shown (highest possible score is 5). The five dimensions or driving style factors are:

- Speed; frequency of driving fast and exceeding the speed limit
- Deviance; frequency of jumping the lights and overtaking on the inside
- Carefulness; frequency of driving cautiously and adjusting speed to others
- Lane-change behaviour; frequency of lane changes
- Focus; ability to ignore distractions.

In general the figure shows the relatively high scores on Carefulness and Focus and average scores on Speed and Lane-change behaviour.

Main effects of type of Trip were found on all driving style factors except for Focus (Speed: F(2,297)=25.9,p<0.001; Deviance: F(2,297)=7.9,p<0.001; Carefulness: F(2,297)=12.6,p<0.001; Lane-change: F(2,297)=8.6,p<0.001). Bonferroni post hoc tests show that on long trips higher speeds and reduced carefulness are reported compared to short trips. On commuter trips more deviance is reported compared to long trips and more lane-changes and higher speeds compared to short trips. Although these differences in driving style for the three trips are statistically significant, they are very small on the scale from 0 to 5. They may therefore be considered as not very relevant. In the next sections driving styles averaged over the three trips are used in further calculations.

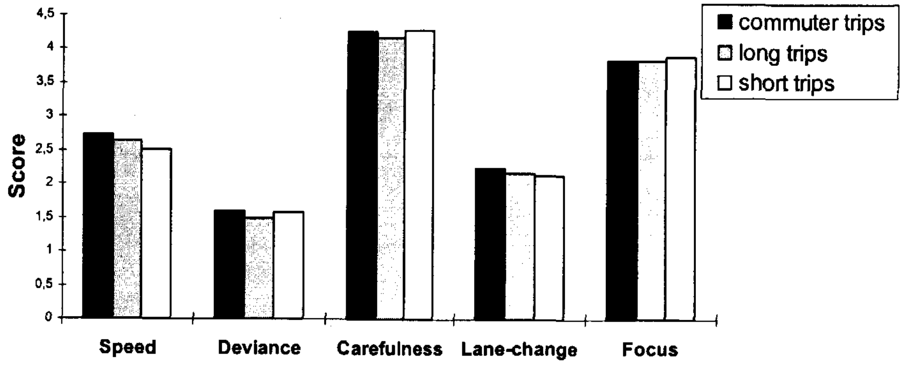

Figure 5-2: Average scores on driving style factors for commuter trips, long trips, and short trips.

Needs versus driver support judgements

When needs are taken as a factor with two levels (1 is important, 2 is unimportant), creating a dichotomy between drivers, it is calculated whether drivers with different needs show a different answering pattern on questions relating to their judgements on driver support systems. The relationship between the two variables is calculated using the chi-square test, because the answers on the judgement questions were on the nominal scale. The most striking differences are shown in table 5-1.

Table 5-1. Judgements on driver support systems differentiated for drivers ranking the needs as important or unimportant (*p<0.05, **p<0.01). The numbers indicate the percentages of those drivers that agree with the given propositions.

		"Obstacle detection increases traffic safety"	"Obstacle Detection will decrease attention"	"Don't like Anti-Collision taking over control"	"ACC improves traffic flow"	"Automated Highway takes away the fun of driving"
General		60%	44%	65%	47%	39%
Expediency	Important	35	39	61	44	44
	Unimportant	69**	47	64	46	39
Own speed	Important	58	48	69	39	56
	Unimportant	61	46	39**	43	32*
Doing other activities	Important	52	55	81	45	55
	Unimportant	55	46	61*	43	42
Safety	Important	63	44	66	49	38
	Unimportant	50	60	60	10*	40
Kick of driving	Important	54	46	71	29	74
	Unimportant	62	42	68	48*	27**
Enjoy surroundings	Important	66	44	66	34	50
	Unimportant	65	47	58	56*	41
Driving relaxed	Important	63	44	66	47	38
	Unimportant	56	78*	67	22	56

The table shows that there are some important differences in judgement on driver support systems between drivers with different needs: There are much less drivers who like expediency that agree with the fact that obstacle detection will increase traffic safety, than drivers who don't think expediency is important. Drivers for whom it is important to drive at their own speed have a stronger negative attitude towards driver support systems taking over control (and thereby taking away the fun of driving). The same accounts for the drivers who like the kick of driving, and they're also less convinced that ACC improves traffic flow. Drivers who think it's important to drive in a relaxed way are less negative about driver support systems decreasing attention as drivers who don't stress the importance of relaxed driving.

Needs versus driving styles

Table 5-2: Spearman rank correlation coefficients between a driver's needs and reported driving style (*p<0.05, **p<0.01).

	Speed	Focus	Carefulness	Deviance	Lanechange
Needs:					
Safety	-0,15**	0,02	0,19**	-0,06	-0,03
Driving relaxed	-0,13**	0,07	0,11*	-0,08	-0,12**
Kick of driving	0,21**	-0,12*	-0,10*	0,08	0,11*
Expediency	0,46**	-0,06	-0,19**	0,10*	0,18**
Own speed	0,11*	0,07	-0,18**	0,04	0,10*
Other Activities	-0,03	0,03	-0,01	0,03	-0,04
Enjoy surroundings	-0,23**	-0,04	0,08	-0,12*	-0,05

Table 5-2 shows the correlations between the ranked values of the needs (averaged over the three kinds of trips) and the scores on the five factors of the driving style questionnaire Speed, Focus, Carefulness, Deviance, and Lanechange (also averaged over the three trips). The correlations are low, but it can be seen that the need for safety, driving relaxed and enjoying the surroundings is negatively correlated with the Speed driving style. In contrast the need for safety and driving relaxed is, not suprisingly, positively correlated with carefulness. The need for the kick of driving, expediency and driving on your own speed is positively correlated with Speed and negatively correlated with Carefulness. The ability to ignore distractions (Focus) is negatively correlated with the kick of driving and the frequency of showing deviant behaviour (Deviance) is not correlated with any of the driver needs.

When needs are taken as a factor with two levels (1 is important, 2 is unimportant), creating a dichotomy between drivers, the difference in driving style can be calculated between drivers who rank each of the needs as important or unimportant. Between subjects analyses then confirm the relations that were found with the Spearman rank correlations. That is, drivers who like the kick of driving report a high speed, less careful driving style with more lane changes. Drivers who like expediency report to drive faster, be less careful, and change lanes more frequently. The same effects are found for drivers who like to drive at their own speed. Finally, drivers who like to enjoy the surroundings while driving report to drive slower and with a lower deviance.

5.4 Discussion and conclusions

Before embarking on a discussion of the results, it is necessary to acknowledge the possibly unrepresentative nature of the sample used in this study. Although gender, age and mileage profile are in accordance with that of the Dutch drivers population, it might be argued that the population of members of the Dutch automobile association (ANWB) is not fully representative of the whole Dutch drivers population. Automobile Association members might be more concerned about their safety, because membership assures drivers of immediate help with any car problems.

5.4.1 Judgements on driver support systems

With respect to the judgements that were reported towards Obstacle Detection, Anti-Collision, Adaptive Cruise Control and the Automated Highway, it can be concluded that the respondents were quite positive about the increase of traffic safety as a result of the introduction of one of the four driver support systems. However, they also report some distinctly negative attitudes, like giving away the control over the vehicle or being afraid that the car will brake at dangerous moments. These results are in accordance with for example Bekiaris et al. (1997), who carried out an international questionnaire survey for the SAVE project (The SAVE system continuously monitors the driver for signs of impairment, issues warnings, and in case of emergency takes over vehicle control), which indicated that the driver population is reluctant to release vehicle control, but is willing to accept it in emergency situations. Smeekes et al. (1996) studied attitudes towards the automated highway both in the Netherlands and in the USA by means of a questionnaire survey. Their major conclusions were that awareness of the Automated Highway is low and the general distrust high. Most negative judgement was found with respect to the phenomenon “the independent vehicle”, which can be compared to the judgements on giving away vehicle control in this study.

The first hypothesis states that drivers’ needs are related to their judgements of driver support systems. In some respects this hypothesis is confirmed. For example, drivers who like to drive at their own speed are much more convinced that they don’t like a Collision Avoidance System (CAS) taking over control. Drivers who like the kick of driving are much more convinced that the Automated Highway will take away the fun of driving.

These differences can be explained by pointing to the contrast between on the one hand driver support aspects of giving away the control of driving, and on the other hand the need of preferring the kick of driving or driving at your own speed. But the relationship between a driver's needs and his judgements on aspects of driver support systems must not be exaggerated. The results show that for a lot of other judgements no differences between drivers with opposite needs can be seen. It is therefore concluded that a driver's specific needs do not influence their judgements about aspects of driver support systems to a large degree; at least not those aspects that were used in this questionnaire.

5.4.2 Needs and driving styles

With respect to the various needs, the majority of the respondents ranked safety as their most important need during a trip. Driving relaxed was also considered to be very important, whereas expediency and the kick of driving were considered to be very unimportant.

Tertoolen (1994) and Tertoolen & Verstraten (1995) find different results of what aspects drivers consider to be important. They asked respondents what aspects they believe are important when driving their cars. Speed, comfort and independence are mentioned as the most important advantages of the car. Safety aspects are not considered important.

The second hypothesis is confirmed, stating that driving styles differ between types of trips and needs don't. No evidence has been found for a difference in need structure for different kinds of trips, whereas on the reported driving styles, a difference between trips is found. This is in line with the reasoning of the hierarchical framework of driver behaviour: drivers adjust their driving style to different situations in order to satisfy their higher level needs, which stay the same. However, although statistically significant, differences between the trips are very small and therefore not very relevant to be considered in further research. Moreover, other researchers have shown that speed, in particular, is a consistent and a reliable measure of driving style over time and over *locations* (Summala et al., 1984; Rajalin, 1994). It is therefore concluded that needs and driving styles can be seen as stable traits that can be different between drivers but not between trips. I.e. drivers don't change their needs and accompanying driving styles when going on different trips like commuter or holiday trips.

A relationship was found between needs and some of the self reported driving styles, confirming the third hypothesis. Drivers with certain needs report driving behaviour different from drivers with other needs. In this case, drivers who rank expediency as an important need, report to drive faster, are less careful and change lanes as much as possible. The same applies to drivers who like the kick of driving and also report a less focused driving style. The group of drivers who rank safety important, reports a lower speed and more careful driving style. Also driving relaxed and enjoying the surroundings result in a lower speed driving style.

From correlations alone it is difficult to state whether driving styles follow the needs or the other way around. Parker et al. (1998), who studied aggressive driving behaviour using a self-report questionnaire, found a positive relationship between aggressive driving styles and a positive attitude towards the kick of driving. They concluded that it's not possible to state whether the intentions follow the behaviour or the other way around. It may be that those who get involved relatively more often in aggressive driving behaviour, perhaps quite enjoy the kick they get. Alternatively, it may be that those with this attitude, allow themselves to get into situations where an aggressive driving incident is more likely.

In the current study the correlations confirm the link between needs and driving styles as predicted by the hierarchical framework of driver behaviour. This framework gives ground for indicating the direction of influence between needs and driving styles: A higher level need at the strategical level determines the way in which people are driving at the tactical or operational level. Although most of the reported correlations were low and reached statistical significance by virtue of the sample size, they give an indication of understanding driving behaviour in terms of more generally applicable traits that drivers may have. This conclusion is used in the experimental studies that are described in the next two chapters. An important selection criterion for the subjects participating in the experiments is their self-reported driving style. This gives the opportunity to predict their behaviour and reactions to driving with driver support systems, because we can expect this to be in line with their higher level needs. The experimental studies also give the opportunity to validate reported driving styles against "real" driving behaviour in the simulator.

6. A driving simulator experiment on Adaptive Cruise Control (ACC)

This chapter describes an experimental study that is conducted in the driving simulator at the Centre for Environmental and Traffic Psychology (COV) at the University of Groningen, in which hypotheses were tested with respect to driving style groups and their reactions to Adaptive Cruise Control.
In the experiment, four groups of driver participants, who differed on reported driving styles concerning Speed (high speed = driving fast) and Focus (high focus = the ability to ignore distractions), drove the same motorway route in the driving simulator with and without an ACC system. It was expected that especially these driving styles are important in a driver's reaction to ACC, because of the reduced control drivers will have on speed, and the enhanced susceptibility to distractions when using the system, which will create safety hazards.
The results of the experiment show behavioural adaptation with an ACC in terms of higher speed, smaller minimum time headway and larger brake force. It is concluded that all drivers adapt their behaviour with respect to speed according to expectation, irrespective of predetermined driving style. Most drivers evaluated the ACC system very positively, but the undesirable behavioural adaptations observed should encourage caution about the potential safety of such systems.

6.1 Introduction

Adaptive Cruise Control systems (ACC's) are driver support systems, capable of regulating both speed and following distance (see chapter 2 for a more extensive description). They are primarily designed by the manufacturers as comfort enhancing systems. Taking over parts of the driving task means that ACCs potentially reduce workload. Finally, in principle they are likely to have a positive effect on traffic safety and economy because an ACC may maintain a perfect, safe and short headway to the vehicle in front. By means of smoother acceleration and deceleration profiles, the system potentially contributes to a more stable traffic flow and enables driving at shorter headways and higher speeds, which increase roadway capacity.

To what extent ACCs will fulfil all these promises in practice will depend, in part, on the technical feasibility of efficiently handling deceleration and time headway. Clearly, another important factor in the success of these systems will be the way in which drivers will use the system, the drivers' acceptance of the system and their reaction in terms of driver behaviour. Although ACC is not explicitly devised as a safety enhancing system, it is still important to evaluate the behavioural effects of such systems in terms of traffic safety because it would be unacceptable for any such system, designed as comfort enhancing, to have a negative impact on traffic safety. Such evaluations should also take into account the possibility that drivers will fail to accept or behaviourally adapt to it in undesirable ways. Behavioural adaptation has been identified by the OECD (1990) as a significant issue, "drivers employ the vehicle technology available to them in order to suit their driving purpose, motivation, driving style and current physical process."

6.1.1 Behavioural adaptation

A number of studies investigated drivers' reaction to ACC's in terms of their behavioural adaptation and acceptance of the system. For instance, Nilsson (1995) found in a driving simulator study, that subjects driving with an ACC spent more time in the left lane than subjects driving without ACC. Approaching a stationary queue resulted in more collisions among ACC users than among unsupported drivers, possibly because of drivers having too high expectations leading to belated and abrupt interventions. Heino et al. (1995) found, also in a driving simulator study, that driving with an ACC decreased time headway and variability in headway. Driving with the system also decreased (subjective) workload. Ward et al. (1995) conducted a field trial with a prototype ACC and also found evidence of behavioural adaptation: drivers set the ACC at higher speeds and at shorter headways compared to unsupported driving. Drivers were also observed to have a larger standard deviation of the lateral position on the road with ACC compared to driving without. It was concluded that the system was used in a manner that may improve traffic flow and harmonisation, but only if higher speeds and shorter headways do not increase the rate or severity of accidents.

With respect to higher speeds with ACC, Sayer et al. (1995) found in a study of an ACC system driven in an actual motorway environment, that participants drove at slightly higher mean velocities under the manual condition as compared with ACC. Also, Hogema & Janssen (1996) showed in a simulator study that subjects select a lower free-driving speed compared to their driving with ACC. In the critical scenarios where the subject had to take over control from the ACC, a later reaction was found.

6.1.2 Following distance

An ACC presets the time headway with which the car is following a lead car, so it is important that, apart from being able to bring the car to a safe stop in case the lead vehicle suddenly stops, this following distance is in accordance with the driver's time headway choice. In the literature, several factors have been identified that influence the headway at which drivers choose to drive. Some authors have stressed the importance of task-related factors with regard to preferred time headway. For instance Brookhuis et al. (1991) reported an increase in time headway when using a car telephone while driving, which can be regarded as an additional task competing for attention. Choice of time headway has also been associated with temporary state-related factors. Fuller (1984), for example, reported a time-on-task effect on time headway for older truck drivers in the late shift. After seven hours of driving, time headway increased strongly, accompanied by verbal reports of performance decrements, drowsiness and exhaustion. Other authors associated choice of time headway with personality factors. For example, Zuckerman and Neeb (1980) found a positive correlation between the sensation seeking score and reported driving speed, whereas Heino et al. (1992), using a realistic car-following task, reported a smaller preferred time headway for sensation seekers than for sensation avoiders. Ward et al. (1995) examined the effects of ACC along a motorway in moderate traffic, where participants were also divided into high and low sensation seekers. They found that the high sensation seekers set the ACC at shorter headways than were normally driven. De Vos et al. (1996) carried out a study into the acceptability of short headways in an Automated Highway System (AHS, see for a description chapter 2). The study concluded that, in order to equal the comfort level in dense traffic as experienced daily on the motorway network in rush hours, the AHS headway should be more than 0.86 s, which corresponds to headways observed in normal traffic.

6.1.3 Acceptance

With respect to driver's acceptance of ACC systems, Becker et al. (1994) described a study in which the participants drove with an ACC in real traffic. Their results show that ACC is perceived as a comfort-oriented and safety-enhancing system, implying high acceptance. The distance keeping behaviour was experienced very positively and generally classified as acceptable, comfortable, safe and relaxing. Hogema et al. (1994) tested different forms of ACC systems in a driving simulator and found that most

ACC's were considered relatively useful and comfortable. One type of ACC, giving an acoustic feedback signal, was judged to be useless and uncomfortable. Nilsson (1995) found that drivers had a positive attitude towards ACC, and that they found it useful. The subjects expressed a wish to have the ACC in their own car, and thought they would use it often if they had it available. Fancher et al. (1995) reported in an ACC study on local highways, that subjects reported to feel safer using ACC because it maintained a safer following distance and required fewer interventions by the driver than conventional cruise control. Regarding the issue of automatic braking, subjects were almost unanimous in their objection to automatic braking, because it crossed the red line that dictates who controls the vehicle. This is in line with the finding that perceived control over the environment in general is a major intervening variable in the stress appraisal process (e.g. Glass and Singer, 1972; Hockey et al., 1989).

6.1.4 Driving styles and driver needs

The study of individual differences in accident involvement presumes that different degrees of accident involvement are in part a product of differences in driving style. West and French (1993) reported that driving style reflects habitual modes of operating the car on the road. They conclude that self-reports of speed could be used as a surrogate for direct observations of speed. French et al. (1993) used these self-report driving style measures in several studies and found consistent relationships between certain dimensions (particularly speed) and accident involvement. West et al. (1992) also studied driving styles as correlates of individual accident risk and found a link between self-reported driving style (especially speed) and accident risk.

Driving with or without an ACC, drivers have different needs and driving styles, which in turn may influence their (behavioural) reaction to ACC. Hoedemaeker (1996), reporting the results of a questionnaire study about the needs and driving styles of Dutch car drivers, showed that drivers differ in their needs or motivations regarding driving and their reported driving styles (Hoedemaeker, 1996; see also chapter 5). Following the reasoning of the OECD (1990), these needs and driving styles should be taken into account when investigating behavioural adaptation to, and acceptance of, ACC systems because different needs and driving styles would be expected to lead to different reactions. Whenever ACC systems frustrate these needs or preferred driving styles, acceptance of the systems will be low and unwanted or dangerous drivers' reactions may occur. Driving styles regarding speed choice and headway adopted, and the degree to which drivers are distracted by irrelevant events (the so-called focus dimension, West et al., 1992), are expected to be especially important because of the reduced control drivers will have over speed, and the enhanced scope for distractions when using the system, may create safety hazards.

6.1.5 Expectations

In the present experiment hypotheses are tested with respect to behavioural reactions and adaptation when driving with different ACC forms. Driving styles are taken into account by dividing the drivers into four groups with different driving styles and corresponding needs, which might be important in drivers' behavioural reactions and acceptance of ACC systems. Also, preferred time headway might be associated with driving style, instead of only with driving speed or a personality factor like sensation seeking as described above.

Based on the questionnaire study described in chapter 5, groups of drivers were formed based on the driving style factors Speed (high speed = driving fast) and Focus (high focus = the ability to ignore distractions very well). These driving styles are interesting because speed is linked directly to the longitudinal driving task that is supported by an ACC. Focus is interesting because driving with an ACC takes away part of the control over the driving task and therefore may have negative effects on attention and alertness.

The hypotheses are as follows:

1. In accordance with the above mentioned studies it is hypothesised that while driving with ACC, drivers will set higher speeds, have poorer lane position and report less mental load, compared to driving without ACC.
2. The driving style groups will distinguish themselves in their driving behaviour; i.e. high speed drivers drive faster and prefer shorter headways. High focus drivers will show better lane position, with smaller deviations from that lane position. As a compensation for their lower focus, their preferred time headway is larger. High focus drivers will do better performing a secondary task during driving.
3. In reaction to the ACC system, it is expected that high speed drivers will have lower acceptance and, where the system permits it, will overrule the ACC more than low speed drivers will. The reason for this is that an ACC restricts high speed drivers more in driving the way they want. Also their need for the kick of driving (see chapter 5) does not correspond to the functions of the ACC system. When driving ACC that cannot be overruled, the high speed drivers will have an even lower acceptance because the system is even more restrictive. The low focus group will be more distracted when driving with an ACC than the other drivers will.
4. An Adaptive Cruise Control system that adopts a default headway equal or close to their own preferred headway is more acceptable for all drivers than a fixed preset headway.

6.2 Method

6.2.1 Participants

Thirty-eight subjects (25 male, 13 female, between 25 and 60 years of age) were paid for their participation in the experiment. None of the participants had previous experience with the simulator; they were selected from a sample of the members of the Dutch Automobile Association (ANWB), living in the city or the province of Groningen, on the basis of driving experience and their answers on the driving style questions of the questionnaire described in chapter four. These questions are based on the Driving Style Questionnaire (DSQ), which was developed and validated by West et al. (1992). It contains six dimensions of which Speed (made up of items about driving fast and exceeding the speed limit) and Focus (items about driving cautiously and ignoring distractions) were the discriminating factors for the participants in the present study.

This questionnaire was part of a larger survey study with 500 respondents, which is described more extensively in chapter 5. Based on the results of this study the boundaries for high and low scores on the factors Speed and Focus were set. In order to be able to make groups of high and low scores on these factors, the scores have to be normally distributed. Low scores were defined as the first quartile of the scoring range, high scores as the last quartile of the scoring range. Figures 6-1 and 6-2 show the distribution curve of the factors Speed and Focus of this larger survey study.

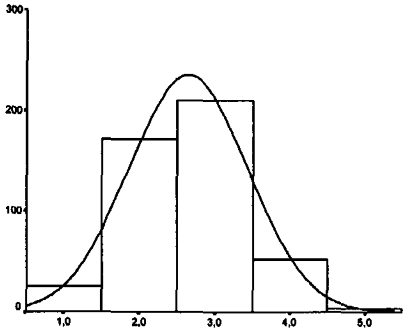

Figure 6-1. Distribution and normal-curve of the scores on the factor Speed (mean=2.7, sd=0.78).

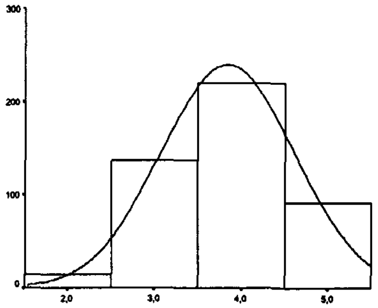

Figure 6-2. Distribution and normal-curve of the scores on the factor Focus (mean=3.8, sd=0.77).

Group 1: high score on Speed (last quartile of the scores, i.e. >= 3.0) and high score on Focus (last quartile of the scores, i.e. >= 4.3)

Group 2: low score on Speed (first quartile, i.e. <= 2.2) and high score on Focus (last quartile)

Group 3: high score on Speed (last quartile) and low score on Focus (first quartile, i.e. <= 3.3)

Group 4: low score on Speed (first quartile) and low score on Focus (first quartile)

For the present experiment new respondents filled out the driving style questions and a general questionnaire about age and driving experience. Only individuals who held a driving licence for at least 3 years, who were driving regularly (more than 50 km a week), and who fitted in one of the four following driving style groups were selected. The characteristics of the participants are shown in table 6-1.

Table 6-1. Characteristics of the participants of the experiment per driving style group.

	Group 1 high speed high focus	Group 2 Low speed High focus	Group 3 high speed low focus	Group 4 low speed low focus
N	10	10	11	7
% male	50%	60%	64%	85%
% female	50%	40%	36%	15%
mean age (sd)	37.1 (11)	41.8 (9.6)	34.9 (11.4)	41.0 (10.6)
km per week (sd)	506 (390)	274 (200)	484 (435)	188 (191)

In the process of assigning subjects to one of the groups, the aim was to match the four groups on sex, age and driving experience (kilometres a week). Post-hoc tests show that there are no statistical differences on these variables between the four groups. The groups are matched, so differences that will be found between the groups on variables measured in the experiment cannot be attributed to differences in sex, age or driving experience, but only to their differences in driving style.

6.2.2 General set-up of the study

The driving circuit that was created in the driving simulator at the Centre for Environmental and Traffic Psychology (described in more detail in chapter 4) was made up of a standard motorway of two lanes of 3.5 m. wide in two directions and a third, emergency lane in both directions. In the middle a guard-rail was visible. Before the experiment started participants practised for about 15 minutes in the normal simulator car and another 15 minutes with the Adaptive Cruise Control (ACC).

Figure 6-3. Picture of the motorway in the driving simulator

Adaptive Cruise Control

In the absence of a leading vehicle the ACC controls speed by keeping the actual speed of the vehicle equal to the reference speed as set by the driver. If a lead vehicle is detected the ACC automatically switches to headway control, which means keeping the actual time headway at the reference time headway implemented in the ACC. In the current experiment three different reference time headways are used: 1.5 s., 1.0 s. and a personally preferred headway indicated by the driver. All participants activated the ACC once at the beginning of each condition by pressing a button and releasing their foot from the gas pedal at the moment they reached the speed they wanted to set. A green LED mounted in the dashboard then indicates that the ACC is switched on. Actual speed could be monitored continuously on the speedometer. Two versions of the ACC system were used, one that did not allow the driver to overrule the system, and one that allowed them to overrule the system whenever they wanted. They could do so by either pushing the gas or the brake pedal. As soon as the gas or brake pedal was released the ACC system automatically returned to the previously set speed. In both versions, the ACC system was always able to bring the vehicle to a safe stop without intervention by the driver. Though perhaps not entirely realistic, this was done because reaction to a failing system was not the subject of this study and would possibly evoke unwanted driver reactions.

All participants drove the simulator on two separate days. They first drove a motorway route without ACC and then with three of the ACC conditions described in Table 6-2. Each condition consisted of the same motorway route in which several different traffic scenarios were presented, including busy as well as quiet traffic, queue driving, merging into the left lane and an emergency stop when driving in a traffic queue.

Table 6-2. Design of the experiment with a total of seven conditions. All subjects drove in all conditions.

Day	ACC?	THW (in s)	Version
1	no ACC	n.a.	n.a.
1/2	ACC	preferred	Overrulable
2/1	ACC	preferred	non-overrulable
1/2	ACC	1.5	overrulable
2/1	ACC	1.5	non-overrulable
1/2	ACC	1.0	overrulable
2/1	ACC	1.0	non-overrulable

To prevent confusion, participants drove the versions of the ACC that could be overruled and those which could not be overruled on different days. The order of time headway conditions was balanced across participants. Participants were instructed to drive as they would normally do on the Dutch motorways and to use the ACC as much as possible, only overruling it when they considered this really necessary.

Preferred time headway was measured in a separate session. In this session participants were instructed to follow one lead car at a ‘small but safe distance’. The initial position from which the participants were allowed to adjust their headway was either very close or at a large distance from the vehicle in front. The first lead car started at a large distance from the participant. After the participants had followed the lead car for 30 s at their preferred headway, the vehicle turned off and another vehicle merged in front of the participant at a very close distance. Again participants were instructed to follow the lead car at a ‘small but safe distance’.

6.2.3 Data collection and analysis

Driving performance measures included speed, time headway (the time interval between two vehicles in car-following), time to collision (following distance divided by the relative speed of the main car and the lead car), position of gas and brake pedal, and lateral position on the road, all sampled at 10 Hz.

Acceptance of the different ACC conditions (differing in time headway and overrulability) was assessed by a standardised acceptance checklist (Van der Laan et al., 1997), measuring perceived usefulness and perceived comfort of the system. The technique is described in more detail in chapter four.

Mental effort of each condition was assessed by a self-rating on perceived invested mental effort; the Rating Scale Mental Effort (RSME, Zijlstra & Van Doorn, 1985).

Attention or Focus is measured by means of the secondary task method. By letting the participants perform an extra task while driving, it is possible to measure the amount of distraction caused by this task. In this experiment participants had to add up the total length of traffic congestions that are reported through the car-radio (the same task was also used by Cnossen, 1996).

Multivariate Analysis of Variance was applied for the within subjects factors ACC (2 levels: no ACC and ACC), Overrulability (2 levels), Traffic density (2 levels: quiet and busy traffic), and time headway-condition (3 levels: 1.5 s, 1.0 s and preferred). Between subjects factors were Speed-group (fast and slow drivers with 2 levels) and Focus-group (high and low focus drivers with 2 levels).

6.3 Results

This describes the results of the experiment, and is divided into four subsections. These subsections do not correspond completely with the four hypotheses that were formulated in section 6.1.5.

First the effects on driving behaviour with ACC are described (hypothesis 1) together with the differences in this driving behaviour between the driving style groups (hypothesis 2). Effects on time headway are described in the next section (also hypothesis 2), and results on subjective measures like perceived mental effort and acceptance are described in the third subsection (hypotheses 3 and 4). The last subsection shortly describes the results obtained during secondary task performance.

6.3.1 Driving behaviour with and without ACC

Driving speed is found to be strongly influenced by traffic density (main effect quiet vs busy traffic: $F(1,34)=923.1, p<0.001$). Effects of ACC on driving speed are also influenced by traffic density (interaction ACC*Density: $F(1,34)=6.7, p<0.01$). In quiet traffic ACC increases driving speed much more than in busy traffic, but still a main effect of ACC over both traffic densities indicates a general increase in speed when driving with ACC ($F(1,34)=48.5, p<0.001$). In quiet traffic average speed without ACC was 107 km/h, with ACC it was 115 km/h (average set speed in the ACC: 126 km/h).

The high and low speed driving style groups differed significantly in their driving speeds (main effect speed group: $F(1,34)=41.4, p<0.001$), but in quiet traffic when they were free to choose their own speed this effect is more pronounced (Interaction Speed group*Density: $F(1,34)=13.6, p<0.001$). Figure 6-4 shows the effects on ACC, traffic density and Speed group.

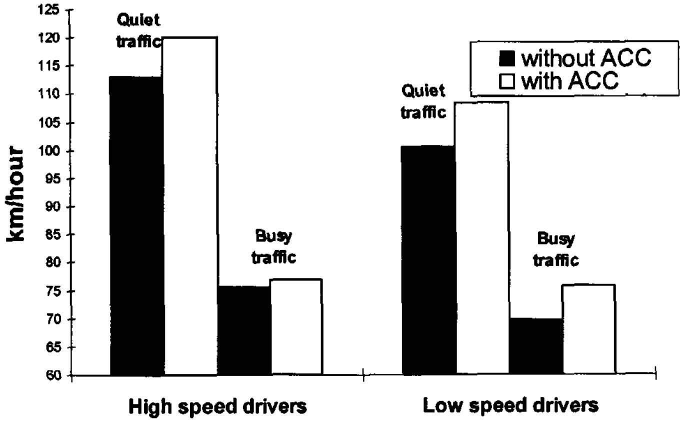

Figure 6-4. Mean velocity (in km/h) in quiet and busy traffic, with and without an Adaptive Cruise Control, for high and low speed drivers.

In combination with the higher velocities with ACC, a main effect of ACC was also found on the percentage of the time that was spent in the left lane ($F(1,34)=6.1, p<0.02$). Also high speed drivers drive more in the left lane than low speed drivers ($F(1,34)=31.1, p<0.001$), in accordance with their high and low velocities.

In general in quiet as well as in busy traffic the standard deviation of the lateral position (sdlp) increases when driving with an ACC ($F(1,34)=10.7, p<0.002$) as compared to driving without an ACC. It increases more when driving in busy traffic compared to driving in quiet traffic (interaction ACC*Density: $F(1,34)=5.0, p<0.03$), because the low speed drivers decrease the sdlp in quiet traffic. This results in a three-way-interaction Speed group*ACC*Density ($F(1,34)=4.9, p<0.03$). Figure 6-5 shows the effects.

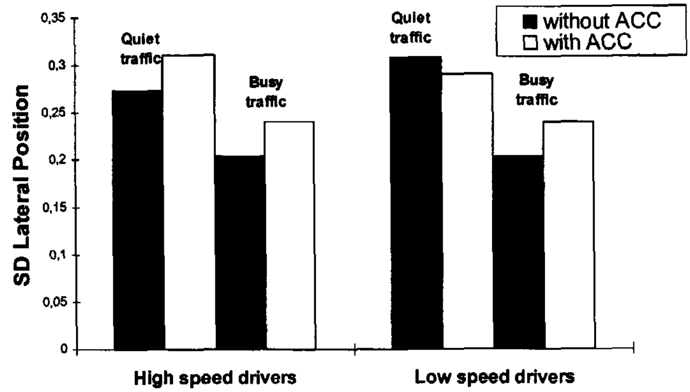

Figure 6-5. Standard Deviation of the lateral position (in metres) in quiet and busy traffic, with and without an Adaptive Cruise Control, for high and low speed drivers.

In one of the scenarios participants were driving in a traffic queue, when suddenly the car in front of the subject's car braked to come to a complete stop. The vehicle had to come to a complete stop and because the ACC was not active in low gear, drivers eventually had to brake themselves in order to perform this emergency stop correctly. In this scenario two main effects of ACC were found, indicating that the average maximal braking was larger ($F(1,34)=3.8, p<0.06$) and that the average minimal time headway was smaller ($F(1,34)=30.3, p<0.001$) with ACC.

Figure 6-6 shows the effects on maximal braking of ACC and the interaction effect of Speed group and ACC ($F(1,34)=3.7, p<0.06$). The effects indicate that the high speed drivers brake harder overall and do not change this when driving with ACC, but low speed drivers do increase their braking with ACC in this situation, which makes the initial group differences disappear.

Figure 6-7 shows the effects on minimal time headway of ACC, Speed group ($F(1,34)=6.1, p<0.02$), and the interaction effect of Speed group and ACC ($F(1,34)=3.6, p<0.06$). Note that minimal time headway is the lowest value found when driving in busy traffic. Again, when driving without ACC group differences are clear, i.e. large time headways for low speed drivers and small time headways for high speed drivers, but driving with an ACC system minimises these group differences; everyone drives with a smaller similar time headway.

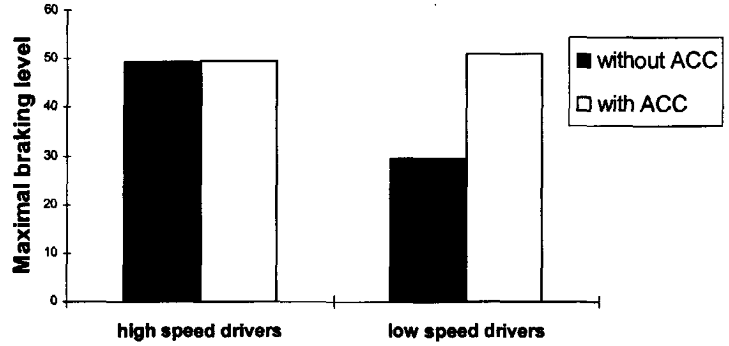

Figure 6-6. Average maximal usage of the brake pedal expressed as the percentage of a complete push down of the brake pedal (=100%), shown for high and low speed drivers with and without ACC, when lead cars performed an emergency stop driving in a traffic queue.

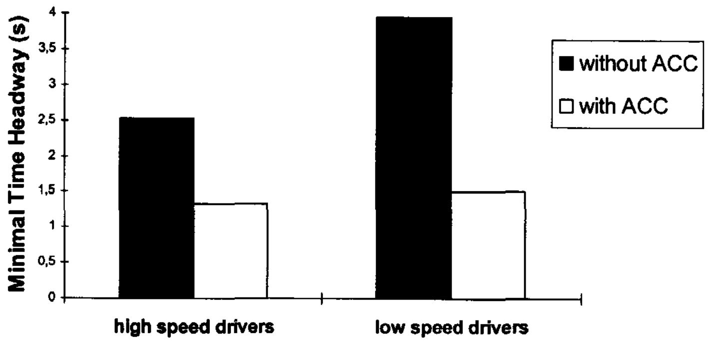

Figure 6-7. Average minimal time headway in seconds, shown for the high and low speed drivers with and without ACC, when lead cars performed an emergency stop driving in a traffic queue.

When participants had to merge into the left lane because of closure of the right lane, three main effects of ACC were found:

1. The average manoeuvre velocity increased with ACC ($F(1,33)=7.7, p<0.01$).
2. The accepted gap-distance was lower with ACC ($F(1,29)=12.3, p<0.002$).
3. The time it took to merge into the left lane decreased with ACC ($F(1,31)=5.7, p<0.02$).

The effects show that drivers perform the manoeuvre more efficiently while driving with an ACC as compared to driving without an ACC.

6.3.2 Time Headway

Preferred Time Headway

Starting at a very short distance from the vehicle in front, participants chose an average preferred time headway of 1.8 s. (SE 0.15), while starting at a very long distance participants only closed in on the lead vehicle to a headway of 2.2 s. (SE 0.14), showing a delay in the preferred time headway ($F(1,24)=10.8, p<0.002$).

A main effect of Speed group ($F(1,34)=4.1, p<0.05$) indicates that high speed drivers prefer a smaller time headway (1.7 s, SE=0.17) than the slow speed drivers (2.3 s, SE=0.19). No main effect of Focus-group was found. Remember that it is this personal preferred time headway that is implemented in one of the ACC conditions. The first four bars in figure 6-8 indicate the preferred time headways of the four driving style groups.

Actual Time Headway without ACC

When driving in a traffic queue without ACC, the minimal time headway the participants chose was 3.2 s (SE=0.43), with a main effect for Speed group ($F(1,34)=4.9, p<0.03$). The second four bars in figure 6-8 indicate the actual time headways of the four driving style groups. In comparison with the preferred time headways these actual values, found in busy traffic are quite high. This could be due to the fact that the normal car condition was always the first condition. Another reason could be that distance keeping in simulator traffic might be more difficult compared to normal traffic because of the two-dimensionality.

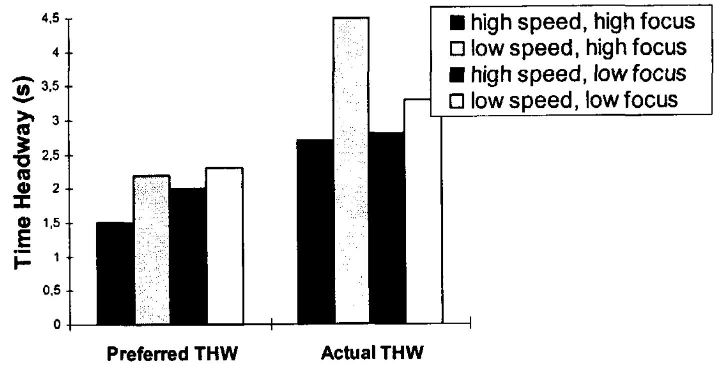

Figure 6-8. Preferred and Actual time headway of the four driving style groups.

Time Headway conditions

Participants drove with three different time headway conditions in the ACC: 1.0 s, 1.5 s, and the personal preferred time headway value measured separately.

In terms of driving behaviour a main effect of time headway condition was found on the standard deviation of the lateral position (sdlp) ($F(2,30)=3.7, p<0.04$), indicating that sdlp is the largest in the 1.5 s headway condition.

Effects on the percentage of time drivers overruled the ACC by pressing the gas pedal show that the driver's own preferred THW condition is overruled the most (main effect thw condition: $F(2,32)=4.3, p<0.02$). This overruling behaviour is different for high and low speed drivers (interaction Speed group*THW condition: $F(2,32)=3.0, p<0.06$). Figure 6-9 shows that high speed drivers overrule the 1.0 s ACC headway the least, whereas low speed drivers overrule the 1.5 s ACC headway the least. When assuming that drivers overrule the system whenever they experience it as not convenient, we can infer that high speed drivers like the 1.0 s ACC the most and low speed drivers prefer the 1.5 s ACC.

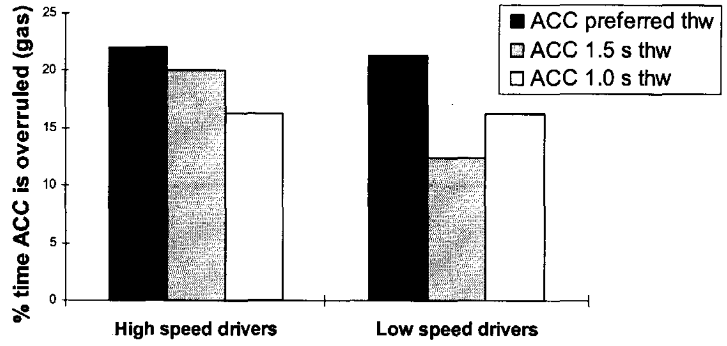

Figure 6-9. Percentage of the time high and low speed drivers overruled the three time headway conditions of the ACC.

6.3.3 Subjective measures

Mental effort

The responses on the Rating Scale Mental Effort (RSME) show that the participants experienced driving with an ACC as less effortful than driving without an ACC ($F(1,34)=21.4, p<0.001$).

Acceptance

Figure 6-10 presents the average scores on the acceptance questionnaire that the participants completed after driving in each condition. Two main factors can be distinguished on this questionnaire: a comfort scale and a usefulness scale. The results indicate that high speed drivers do not appreciate the non-overrulable versions of the ACC, whereas low speed drivers perceive both versions as comfortable and useful (interaction Speed group* Overrulability: on comfort $F(1,34)=7.8, p<0.01$, on usefulness $F(1,34)=16.7, p<0.001$).

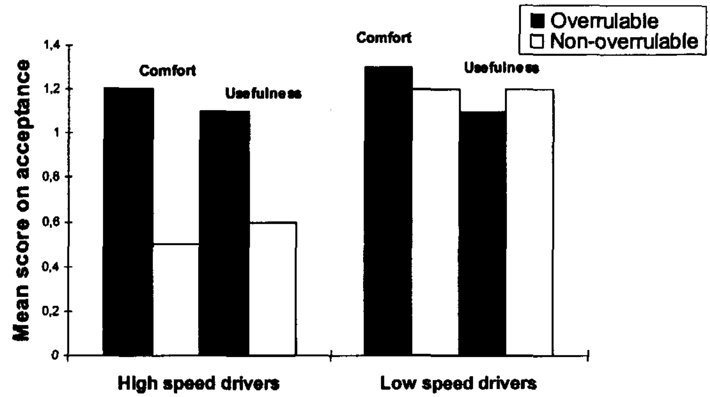

Figure 6-10. Comfort and usefulness scores on the acceptance questionnaire of the overrulable and non-overrulable versions of the ACC, presented for high and low speed drivers.

No effect of time headway condition was found, implying that participants had no preference for any one of the time headway conditions of the ACC. Also when participants were categorised into new subgroups based on their preferred time headway, again no effect was found of time headway condition.

6.3.4 Secondary task

Secondary task performance during driving (the secondary task consisted of adding up the total length of traffic congestions that were reported through the car-radio) showed no main effect of ACC, so correct answers did not differ when driving with an ACC compared to driving without. Participants had more correct answers when driving in quiet traffic compared to driving in busy traffic ($F(1,34)=4.2, p<0.05$).

Driving behaviour during secondary task performance showed main effects of secondary task (driving with or without performing the task) on driving speed and standard deviation of the lateral position (sdlp). All participants drove slower during secondary task performance ($F(1,34)=57.8, p<0.001$), especially in busy traffic (interaction Sec.task*Traffic density: $F(1,34)=18.9, p<0.001$). Sdlp decreased during secondary task performance ($F(1,30)=25.5, p<0.001$), probably due to their lower speeds. No effects of driving style groups were found.

6.4 Discussion and conclusions

The main objective of the experiment described in this chapter was to assess Adaptive Cruise Control (ACC) with regard to behavioural adaptation and acceptance, taking into account different driving styles of Speed (high speed = driving fast and exceeding the speed limit) and Focus (high focus = driving cautiously and ignoring distractions). Based on these effects, implications could be derived for traffic safety and efficiency with ACC.

6.4.1 Driving style groups

Participants were assigned to different driver groups on the basis of subjective reports. The present experiment shows that self reported differences in driving style are a good predictor of the participant's actual driving styles displayed in the driving simulator. Drivers who score high on the Speed factor of the Driving Style Questionnaire drive faster, more on the left lane of the motorway and with a smaller time headway, than participants who score lower on this factor. The driving style factor Focus does not show any effect on actual driving behaviour in the simulator. It was expected (see hypothesis 2) that a high focus driving style would lead to a better lane position with smaller deviations from that lane position. Also, performing a secondary task while driving was expected to distract low Focus drivers more than high Focus drivers. Either the task wasn't distracting enough to discriminate between drivers that report to be easily distracted or not, or the factor Focus of the driving style questionnaire is not a very strong discriminator between groups of drivers. Either way, one can conclude that it is very difficult to validate the driving style Focus with actual behaviour in the simulator.

The drivers in each driving style group were matched on sex, age, and driving experience. Although post-hoc tests show that there were no statistical differences on each of these variables, a difference in driving experience is conspicuous in table 6-1. The low speed driver groups, and especially group 4 (low speed and low focus), on average drive a lower distance per week than the high speed groups. No striking differences are visible for the four groups with respect to sex and age, but a relationship between driving experience and driving style in terms of speed can be suspected.

6.4.2 Driving behaviour and acceptance of ACC

All drivers in the experiment adapt their behaviour with respect to speed according to expectation, irrespective of predetermined driving style. They drive faster and set higher speeds with Adaptive Cruise Control compared to driving without. Also with respect to lane position, hypothesis 1 is confirmed. The standard deviation of the lateral position increases and drivers are going to drive more on the left lane with ACC. The results also show that drivers on average adopt smaller time headways and that merging manoeuvres are carried out more efficiently with ACC.

ACC was assessed favourably with respect to mental effort, comfort and usefulness (average close to + 1 on the scale -2 to +2). For example Rothengatter & Heino (1994) using the same questionnaire found in a driving simulator study on ACC a usefulness score of 0.34 and a comfort score of -0.18, and Hogema et al. (1994) found acceptance scores of 0.68 and 0.45 on usefulness and comfort. In this experiment the high speed driver group clearly shows their dislike of a non-overrulable ACC, confirming hypothesis 3. Low speed drivers do not have a preference in terms of comfort and usefulness. The high speed drivers' dislike could come from their need for a 'kick of driving', i.e. their control over the car, which is taken away in the non-overrulable ACC. In general though, ACC is viewed very positively, which is encouraging for the future market of telematics applications.

Interaction effects between driving style group and behaviour with or without an ACC were found on minimum time headway and maximum braking level when driving in a traffic queue. Only low speed drivers increased their maximum braking when they had to perform an emergency stop with an ACC. Apparently driving with an ACC forces this particular group to brake hard. Without ACC high speed drivers already have to brake much harder in this situation than low speed drivers, but because of their increased braking level with ACC, initial group differences are almost gone. Furthermore, minimum time headway adopted by low speed drivers decreased much more with an ACC than it did for the high speed drivers, bringing the two groups to the same headway when driving with ACC. This is a quite logical effect because the ACC system, not the individual driver, determines the adopted headway.

The hypothesis that low focus drivers will be more distracted when driving with ACC is not supported in this study. As was explained above, no differential effects at all were found for the focus groups.

Time headway

With respect to the preferred time headways that participants indicated by following a lead vehicle in the driving simulator, it can be concluded that the values are relatively large. However, they correspond to time headway values that were found in other simulator studies. For example Van Winsum (1996) found, in the same driving simulator, for what he called 'short followers' a mean time headway of 1.5 s. and for 'long followers' a mean time headway of 2.9 s. The same participants had indicated their preferred time headway before the experiment by choosing a photograph that indicated the following distance. He concludes that the simulator is a valid instrument for studying car following behaviour, because there was a highly significant difference between preferred time headway groups on the time headway as measured in the simulator.

Group differences with respect to preferred and actual time headway were found for high and low speed drivers according to expectation, but not for high and low focus drivers as was stated in hypothesis 2. Higher values than the preferred time headway values were found for actual time headway when drivers were driving in busy traffic without ACC, but still the difference between the high and low speed drivers is significant. These higher values could be due to the fact that drivers are not forced to drive behind a lead vehicle as closely as possible, as they were in the separate session measuring preferred time headway. Also, compared to time headway values found in real traffic, these values found in the driving simulator are quite high. The standard recommendation for safe following is 2.0 s. Shinar et al. (1997), however, reports that most drivers maintain headways less than 2.0 s and more than 20 % maintain a headway less than 1.0 s. Of all gaps less than 1.0 s 22% are 0.5 s. or less. Before passing, drivers may reduce their headways to 0.5 s.

In hypothesis 4 it was stated that ACC's adopting a default headway equal or close to their own preferred headway are more acceptable for all drivers. This hypothesis is not supported in the present experiment. The three time headway conditions (preferred time headway, 1.5 s. and 1.0 s.) do not differ in perceived comfort or in perceived usefulness. Also, when participants were categorised in new groups based on their preferred time headway, no indication was found that these groups liked the ACC with their "own time headway" more. The results on overruling behaviour, however, do show that high speed drivers overrule the 1.0 s ACC headway the least and low speed drivers overrule the 1.5 s ACC headway the least. When assuming that drivers overrule the system whenever they experience it as not convenient, we can infer that high speed drivers like the 1.0 s ACC the most and low speed drivers the 1.5 s ACC.

6.4.3 Traffic safety and efficiency

In the light of the higher speeds, smaller time headways and more efficient merging manoeuvres that were found when participants drove with ACC, the system seems a promising development in terms of traffic efficiency. Moreover, ACC was assessed favourably with respect to perceived effort, comfort and usefulness.

However, traffic safety is perhaps not served very well by the system as tentatively indicated in the present study. Although from the collected data no real safety implications could be derived, carefulness is implied. Drivers changed their behaviour in ways that might not be beneficial for traffic safety. The participants drove faster and more in the left lane, while swaying more. Accidents did not happen but close following distances certainly occurred more often, which increases accident likelihood (Brookhuis et al., 1994). A follow-up study on ACC time headway, which is of critical importance to this accident likelihood and to driver acceptance is recommended. Also, driving with ACC on road types other than motorways should be tested. In the light of their high acceptance of ACC's, it can be expected that drivers will use this system not only when driving on motorways, but also on other road types like rural roads. Motorways make up a relatively small part of the total road network, so influences of ACC on rural roads could have more widespread implications.

Non-overrulable ACC systems do not need to be tested again, because this study and that of Minderhoud (1999) and Van Wees (1999) show that a non-overrulable ACC is not a likely candidate for future ACC systems.

7. A driving simulator experiment on Adaptive Cruise Control (ACC) on different road types

This chapter describes a second experimental study that is conducted in the driving simulator at the Centre for Environmental and Traffic Psychology (COV) of the University of Groningen. In the experiment, two groups of drivers, who differed with respect to reported driving style in terms of speed, drove on a motorway and on a rural road route in the driving simulator. They drove the same routes with a normal car and with an ACC system with adjustable headway settings. In the previous driving simulator experiment, described in chapter 6, it was found that drivers who differed in their driving style (particularly regarding speed) show different reactions to driving with an ACC. In this study hypotheses were tested with respect to Adaptive Cruise Control (ACC) use on two types of roads: motorways and rural roads.

The results show that there is no difference in acceptance of ACC's on the two different road types. But driving with an ACC on the rural road leads to dangerous overtaking behaviour and delayed reactions to traffic from the right. It is concluded that carefulness is implied with the introduction of ACC's to different road types. Behavioural adaptation may seriously deteriorate traffic safety, particularly on rural roads.

7.1 Introduction

Research into the effects of Adaptive Cruise Control systems has mostly been focused on effects on driving with these systems on motorways. This is because ACC's are primarily intended as comfort systems for driving long distances, like the conventional cruise control. It has also been postulated that the use of these systems may have a positive impact on traffic flow characteristics of motorways (Minderhoud, 1999).

There are several reasons why it is also important to study the effects of ACC's on acceptance and driving behaviour on rural roads. The first one is that if the driver has an ACC system that he/she likes, he/she will want to use it, and that won't be restricted to motorways. The second reason is that at least 80 % of all roads in Europe are rural roads; so motorways are a relatively small part of the total road network. The third reason is that on rural roads traffic safety problems are much larger than on the motorways. Therefore it is very important to find out what the effects on traffic safety in terms of behavioural adaptation will be on these roads.

In the experiment described in this chapter, effects on driving behaviour, acceptance and alertness/activation are investigated when driving on motorways as well as on rural roads, with an ACC that has a driver adjustable headway switch.

7.1.1 Driving on rural roads

Rural roads in The Netherlands make up the largest part of the Dutch roads outside the built-up area. In terms of total length, only 2 % of these roads are motorways (Centraal Bureau voor de Statistiek, 1999). Rural roads are characterised by a great variety of appearances (with or without delineation, closed for slow traffic or not, with or without grade crossings, etc.), but on all rural roads the official speed limit is 80 km/h. Previous studies (see Kaptein & Theeuwes, 1997) show that road users are not able to distinguish roads according to the official road categories, because there were no systematic differences between members of different categories. Theeuwes and Godthelp (1993) developed the concept of Self Explaining Roads (SER) as a means to a safe road design. In a SER environment road users know how to behave and what to expect, simply on the basis of road design.

Traffic safety on rural roads is problematic. 52 % of all traffic deaths were due to accidents on rural roads, whereas 13 % were due to accidents on motorways and 35 % in the built-up area (Rijkswaterstaat, 1993). In spite of the fact that the driving speed is lower on rural roads compared to motorways, the differences in traffic safety can be easily explained by the fact that there is much more interaction with other traffic (among which is much slower traffic) and the smaller lane-width of these roads.

When using ACC's while driving on rural roads, one can expect interactions with traffic scenarios that are specific to the above mentioned properties of rural roads. For example on intersections, where traffic coming from right has right of way, the ACC will only react to lead vehicles in the same lane, which means that drivers will have to overrule the system. Also, overtaking is much more complicated when there's only one lane for traffic in each direction, because the ACC will react to opposing traffic during the overtaking manoeuvre. In general, on rural roads where more traffic interactions are taking place, more situations will occur where ACC's may be unsuitable.

7.1.2 Adjustable headway ACC's

Fancher et al. (1997) describe a field operational test of an ACC where drivers were supplied a car for 2 weeks equipped with an ACC system enabling headway times of 1.0, 1.4 or 2.0 s by means of a driver switch. With respect to the adjustable headways they concluded that this might be an appealing feature for accommodating the preferences of young, middle aged, and older drivers. Fancher et al. (1998) elaborate on the results of this field test. They show that the ACC is the obvious first choice for high-speed driving environments (i.e. motorways), while manual driving is the clear choice on surface streets (i.e. built-up areas). Since travel speeds are closely related to road type, it is not surprising that they also find that speed strongly determines the level of usage. In the speed range from 105 to 121 km/h, over 70% of the driving was done with the ACC in operation, while in the speed range from 72 to 89 km/h this was only 20%. On average, drivers chose to engage the ACC in 50% of all distances covered at speeds above the 56 km/h threshold for cruise engagement. This result appears to indicate that the basic functionality of ACC appeals to a broad range of drivers. On the other hand, individuals who drive more frequently in dense traffic or who drive relatively faster within the traffic stream tended to use the ACC less. That is, as ACC provided more of an impediment to their passing activity or tended to invite cut-ins in dense traffic, drivers were more likely to turn the system off. Moreover, the choice of one of the three time headway settings is related to the driver's age and driving style. Fancher et al. (1998) conclude that a range of time headway settings is needed to cover different driver preferences.

Sayer (1996) reported that an on-road evaluation of a fixed headway ACC system resulted in comments from drivers regarding the need for driver-selectable headways. He recommends a driver-selectable headway of three or four time-headway settings that people can readily discriminate between while driving (in the range of 1.0 to 2.0 s); a minimum time-headway being prudent.

7.1.3 Expectations

In the present experiment hypotheses are tested with respect to driving behaviour, acceptance and activation when driving with an ACC on two different road types: motorways and rural roads. In addition, hypotheses are also tested with respect to differential reactions of two driving style groups: drivers that report to have a high and low speed driving style (see chapter 5).

Based on the results of the previous driving simulator experiment on ACC's (see chapter 6), choices are made for the ACC control strategies of the ACC used in this experiment. Non-overrulable ACC's are not tested further, because it was found that this type of ACC is, for several reasons, a poor candidate for future ACC systems. Also, default time headway values of the ACC are made more extreme (0.6 s and 1.8 s), to increase the chance on finding a difference in perceived comfort or usefulness of these time headways. Finally, high and low Focus groups (a driving style that indicates the ability to ignore distractions) are not manipulated in this experiment. In the previous one it was concluded that this driving style does not distinguish (or at least not measurably) between driving behaviour as measured in the simulator. Driving with an ACC may have negative effects on attention and alertness (activation), so explicit hypotheses about alertness are formulated for all drivers in this experiment.

The hypotheses are as follows:

1. In accordance with the previous experiment (described in chapter 6) it is expected that drivers with ACC will drive faster, with a smaller standard deviation, more often on the left lane, have poorer lane position and report less mental load, as compared to driving without ACC.
2. Taking over on the rural road is more dangerous when driving with an ACC compared to driving without (because of the reaction of ACC to opposing traffic).
3. On rural roads the ACC has to be overruled more often than on the motorway (there will be more situations in which the ACC is not appropriate). Therefore, driving with an ACC will be appreciated more when driving on the motorway compared to driving on rural roads (ACC's are more appropriate on motorways).
4. Driving with an ACC will decrease activation and mental effort. This will be reflected in the subjective scales as well as in the physiological ECG results.
5. When driving with an ACC on rural roads, drivers will have to overrule the system in order to be able to give right of way. Because driver activation will be decreased (see also hypothesis 4), drivers will react later to giving right of way on intersections when driving with an ACC compared to driving without ACC.
6. Drivers with a high speed driving style will drive faster, overtake faster and choose smaller gaps in the opposing traffic compared to drivers with a low speed driving style.
7. ACC's with a short default time headway will be appreciated more by drivers with a high speed driving style and ACC's with a long default time headway will be appreciated more by the drivers with a low speed driving style. When drivers can toggle between headways, this preference will be reflected in their time headway choice. Drivers with a high speed driving style will choose the short time headway more often and drivers with a low speed driving style will prefer to select the long time headway.

7.2 Method

7.2.1 Participants

Thirty subjects (24 male, 6 female, between 25 and 60 years of age) were paid for their participation in the experiment. None of the participants had previous experience with the simulator; they were selected from a sample of the members of the Dutch Automobile Association (ANWB), living in the province of Groningen, on the basis of driving experience and their answers on the driving style questions of the questionnaire described in chapter four. These questions are based on the Driving Style Questionnaire (DSQ), which was developed and validated by West et al. (1992). It contains six dimensions of which Speed (made up of items about driving fast and exceeding the speed limit) was the only discriminating factor for the participants in the present study. A larger study with this questionnaire is described more extensively in chapter five. The same boundaries were used on the factor Speed for the high and low Speed groups as in the experiment described in chapter six. The difference with the participants from this latter experiment is that they were selected on the basis of two driving style criteria (Speed and Focus), whereas the participants of the present study are selected on the basis of only one driving style criteria (Speed).

For the present experiment new respondents filled out the driving style questions and a general questionnaire about age and driving experience. Only persons who held a driving licence for at least 3 years, who were driving regularly (more than 50 km a week) and who fitted into one of the two following driving style groups were selected. The characteristics of the participants are shown in table 7-1.

Table 7-1: Characteristics of the participants per driving style group.

	Group 1 high speed	Group 2 low speed
N	15	15
% male	87%	73%
% female	13%	27%
mean age (sd)	37.4 (6.4)	40.1 (7.9)
km per week (sd)	425 (239)	252 (146)

In the process of assigning subjects to one the groups, the aim was to match the two groups on sex, age and the number of kilometres driven a week. However, group comparisons show that the kilometres driven per week (i.e. driving experience) are significantly different between the two groups ($F\ (1,29)=5.7, p<0.02$). Age and sex do not differ between the groups.

7.2.2 General set-up of the study

Two different driving circuits were created in the driving simulator at the Centre for Environmental and Traffic Psychology (described in more detail in chapter 4).

One was made up of a standard motorway like the one that was used in the experiment described in chapter 6. It was made up of two lanes (width 3.5 m.) in two directions and a third, emergency lane in both directions. A safety fence was visible in the middle. The official speed limit on these Dutch motorways is 120 km/h.

The other driving circuit was made up of rural road of only one lane of 3.0 m. in each direction and no emergency lanes. There were four intersections on which traffic coming from the right had right of way. The distance between the intersections was 2200 m with a slight curve to the left, which was done to enhance the detection of oncoming cars. The official speed limit on these Dutch rural roads is 80 km/h.

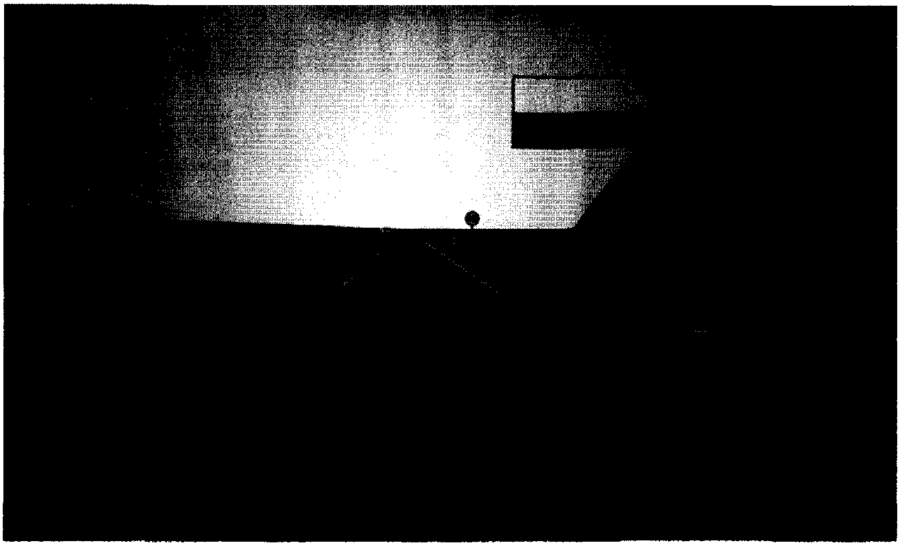

Figure 7-1. Picture of the rural road in the driving simulator

Before the experiment started participants practised for about 15 minutes in the normal simulator car and for another 15 minutes with the Adaptive Cruise Control (ACC) on both driving circuits.

Adaptive Cruise Control

In the absence of a leading vehicle the ACC provides *speed control*, which means keeping the actual speed of the vehicle equal to the reference speed as set by the driver. If a lead vehicle is detected the ACC automatically switches to *headway* control, which means keeping the actual time headway at the reference time headway implemented in the ACC.

In the current experiment two different reference time headways are used: 1.8 s. and 0.6 s. A third ACC system used 1.8 s as default reference time headway, but drivers could switch to 0.6 s and back to the 1.8 s as often as they wanted by means of pushing a button on the right side of the steering wheel. All participants activated the ACC once at the beginning of each condition by pressing a button on the left side of the steering wheel and releasing their foot off the gas pedal at the moment they reached the speed they wanted to set. One of the icons, as displayed in figure 7-2, mounted in the dashboard then indicates that the ACC is switched on and which time headway is active.

Figure 7-2. ACC icons in the dashboard indicating respectively a long (1.8 s) and a short (0.6 s) following distance.

In all three ACC systems drivers were always able to overrule the system whenever they wanted. They could do so by either pushing the gas or the brake pedal. As soon as the gas or brake pedal was released the ACC system automatically switched on again at the previously set speed. By pushing the left button on the steering wheel the ACC system is turned off and has to be reactivated by the procedure described above.

The longitudinal control strategy that is used by the ACC is the same as Minderhoud uses in his SiMoNe simulation model (Minderhoud, 1998). The basis of this strategy is also used in the MIXIC model of TNO (Van Arem et al., 1995). Other technical aspects of the ACC are:
Sensor range: 150 m
Speed range: full (0 - 150 km/h)
Acceleration range: full (-6 m/s^2 - 3 m/s^2)
Net time headway: 0.6 s or 1.8 s
Minimal distance: 2 m.

Table 7-2. Design of the experiment with a total of eight conditions. All subjects drove in all conditions.

Road type	ACC system	THW (in seconds)
Motorway	no ACC	n.a.
Motorway	ACC	1.8
Motorway	ACC	0.6
Motorway	ACC	‘toggle’
Rural road	no ACC	n.a.
Rural road	ACC	1.8
Rural road	ACC	0.6
Rural road	ACC	‘toggle’

The order of time headway conditions was balanced across participants. Participants were instructed to drive as they would normally do on the Dutch motorways or rural roads and to use the ACC as much as possible, only overruling it when they considered this really necessary.

Traffic scenarios

Motorway conditions:

In the motorway conditions quiet as well as busy traffic was presented (order balanced across conditions). Total duration was 7 minutes.

Rural road conditions:

In the rural road conditions four different events were presented on the four lane stretches between the intersections (order balanced across conditions).

1. Nothing happened, the driver was free to choose his/her own speed and driving style.
2. Two cars driving in front of the participant’s car with a speed of 70 km/h. It was not possible overtake because of busy oncoming traffic. In this way car-following behaviour was measured.
3. One car driving in front of the participant’s car, always 10 km/h slower than the participant’s car at a minimum of 60 km/h., teasing the driver to overtake. Opposing traffic started with a gap time of 2 s and increased their gaps with every opposing car with a factor 1.1, meaning that for example 10 cars later the gap was 5.2 s and 25 cars later the gap was 21.3 s. In this way gap acceptance was measured.
4. One truck driving in front of the participant’s car with a speed of 40 km/h, teasing the driver to overtake. Again opposing traffic started with a gap time of 2 s and increased their gaps with every opposing car with a factor 1.1.

On the intersections two events were presented (again the order was balanced across conditions).

1. A car coming from the right but far away, so the driver could easily take right of way.
2. A car coming from the right arriving at the very same moment as the participant's car, so the driver has to decrease his speed and give right of way.

Total duration was 10 minutes.

7.2.3 Data collection and analysis

Driving performance measures included speed, time headway (the time interval between two vehicles in car-following), time to collision (following distance divided by the relative speed of the main car and the lead car), usage of gas and brake pedal, and lateral position on the road, all sampled at 10 Hz.

Acceptance of the different ACC conditions (differing in road type and time headway) was assessed by a standardised acceptance checklist (Van der Laan et al., 1997), measuring perceived usefulness and perceived comfort of the system. This technique is described in more detail in chapter four.

Mental effort of each condition was assessed by a self-rating on perceived invested mental effort: the Rating Scale Mental Effort (RSME, Zijlstra & Van Doorn, 1985). As a physiological measure of mental effort the 0.10 Hz component of the heart rate variability was calculated (see chapter four).

Driver activation of each condition was subjectively assessed by means of the Bartenwerfer Activation scale (Bartenwerfer, 1969). As a physiological measure, average heart rate and heart rate profiles were calculated. Heart rate profiles give the opportunity to monitor heart rate at a more continuous level. The profiles were calculated with a moving window of 30 s with steps of 5 s.

The participants' ECG (Electro Cardio Gram) while resting was measured at the start, in the middle and at the end of each session.

Multivariate Analysis of Variance (MANOVA) was applied for the within subjects factors ACC (2 levels: no ACC and ACC), Road type (2 levels: motorway and rural road), Traffic density (2 levels: quiet and busy traffic on the motorway), and Time headway-condition (3 levels: 1.8 s, 0.6 s and toggle). Between subjects factors were Group (2 levels: fast and slow drivers).

7.3 Results

This section, describing the results of the experiment, is divided into four subsections, which follow more or less the order of the hypotheses that were formulated in section 7.1.3.

First the main effects of ACC and Road type are described based on hypotheses 1 and 2. Then the results in terms of acceptance of the ACC system are described (hypothesis 3). In the next section results on mental effort and activation are described based on both subjective reports and physiological heart rate measurements (hypotheses 4 and 5). Individual differences between the driving style groups are discussed in the last section based on hypotheses 6 and 7.

7.3.1 Main effects of ACC and Road type

Driving speed on the motorway is strongly influenced by traffic density (main effect quiet vs. busy traffic: $F(1,28)=413.8, p<0.001$). Effects of ACC are also influenced by traffic density (interaction ACC * Density: $F(1,28)=5.2, p<0.03$). In quiet traffic, when participants are free to choose their speed, ACC decreases driving speed, which is in the opposite direction as was expected. In busy traffic, however, ACC increases driving speed. On the rural road there were no busy and quiet traffic scenarios, and on the lane stretch where nothing happened (see section 7.2.2) no effect of ACC on driving speed was found. This leads to an interaction effect of road type and ACC ($F(1,26)=7.2, p<0.01$), indicating that ACC affects driving speed on the motorway but not on the rural road. In figure 7-3 average driving speed is shown for the motorway and the rural road, with and without ACC. Effects on driving style group differences will be discussed in section 7.3.5.

The average set speed on the ACC on the motorway was 124.2 km/h. The average set speed on the ACC on the rural road was 85.6 km/h.

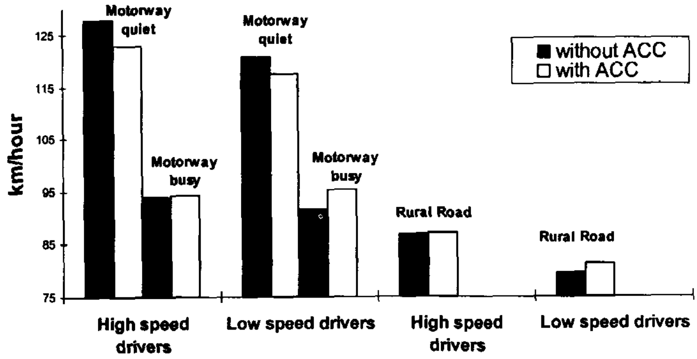

Figure 7-3. Mean driving speed with and without ACC, on quiet and busy motorways and the rural road.

The standard deviation of the velocity decreases according to expectation when driving with ACC on the motorway ($F(1,28)=34.8, p<0.001$) and on the rural road ($F(1,26)=88.6, p<0.001$). On the motorway, the effects of ACC are also influenced by traffic density (interaction ACC * Density: $F(1,28)=24.5, p<0.001$). In busy traffic the standard deviation of the velocity decreases much more compared to quiet traffic conditions. Figure 7-4 shows these effects.

On the rural road another effect of standard deviation of velocity was found on time headway condition ($F(2,25)=26.3, p<0.001$). Driving with an ACC with a short default time headway of 0.6 s, increases the standard deviation, whereas the other two time headway conditions decrease the standard deviation velocity (not shown in the figure).

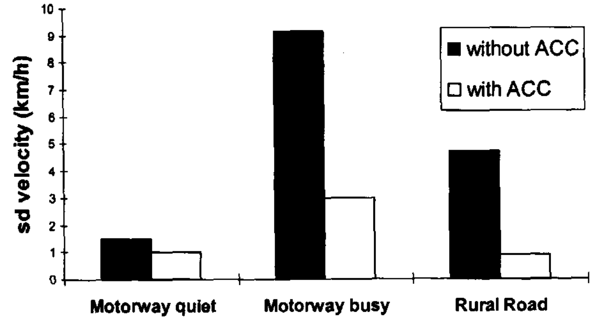

Figure 7-4. Standard deviation of the velocity with which participants drove on the motorway and on the rural road, with and without ACC.

Driving with ACC did not show any effects on the standard deviation of the lateral position (sdlp). Type of road did show an effect ($F(1,27)=25.2, p<0.001$). Sdlp is smaller on the rural road compared to quiet traffic on the motorway. On the motorway driving in busy traffic leads to a smaller (!) sdlp compared to quiet traffic ($F(1,28)=40.7, p<0.001$).

The expectations about driving on the left lane on motorways and reported mental load are confirmed. All drivers drive more often on the left lane with ACC ($F(1,28)=5.5, p<0.03$). This effect is influenced by traffic density (interaction ACC * Density: $F(1,28)=6.2, p<0.02$, main effect Density: $F(1,28)=173.3, p<0.001$). In busy traffic much more driving on the left lane is found with and without ACC. The time headway setting of the ACC is also of influence on the time spent in the left lane. In quiet traffic the short time headway of 0.6 s leads to less driving in the left lane compared to the other time headway settings, whereas in busy traffic the short setting leads to more driving in the left lane ($F(2,26)=27.8, p<0.001$). Related to the time spent in the left lane is the number of times drivers switch between left and right lanes on the motorway. This number increases significantly when driving with an ACC ($F(1,28)=4.5, p<0.04$).
The effects on mental load are further described in section 7.3.3.

Driving with an ACC leads to smaller time to collision values on the motorway ($F(1,27)=6.2, p<0.02$), and to smaller time headways in the car-following scenario on the rural road ($F(1,25)=10.8, p<0.003$).

A main effect of Road type was found for the percentage of time drivers overruled the ACC by pressing the brake or the gas pedal ($F(1,27)=11.4, p<0.002$). The effect shows that on the rural road drivers overrule the ACC more often than on the motorway, which confirms the third hypothesis. In general, drivers overrule the ACC more often by using the gas than by using the brakes ($F(1,27)=36.9, p<0.001$). See figure 7-5.

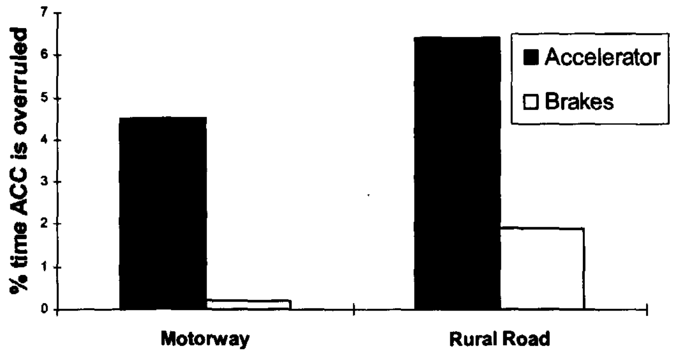

Figure 7-5. Percentage of the time that drivers overruled the ACC system by either using the accelerator pedal or the brakes.

The long time headway condition of the ACC is the one that is overruled the most by the drivers ($F(2,26)=3.0, p<0.07$). When assuming that drivers overrule the system whenever they experience it as not being convenient at that moment, we can infer that especially on the motorway the long time headway of 1.8 s is experienced as being quite inconvenient.

When drivers on the rural road overtake a lead car, they chose a smaller gap between the oncoming cars in the opposite lane when they were driving with an ACC ($F(1,20)=6.3, p<0.02$). Note that the degrees of freedom are smaller because not all drivers in the experiment actually did make the overtaking manoeuvre.

When approaching the intersections on the rural road where a car from the right was visible (see description of traffic scenarios in section 7.2.2), drivers could either release the gas pedal when they were driving without ACC, or, when driving with ACC, they could overrule the system by pressing the brake pedal. The time interval to either reaction differed significantly between driving with or without an ACC ($F(1,24)=4.9, p<0.04$), and between the driver groups ($F(1,24)=5.4, p<0.03$). The first effect confirms the hypothesis (no. 5) that drivers will react later to giving right of way on intersections when driving with an ACC. The second effect follows directly from the fact that the low speed driver group drives slower and therefore has more time left when approaching the intersection. See figure 7-6.

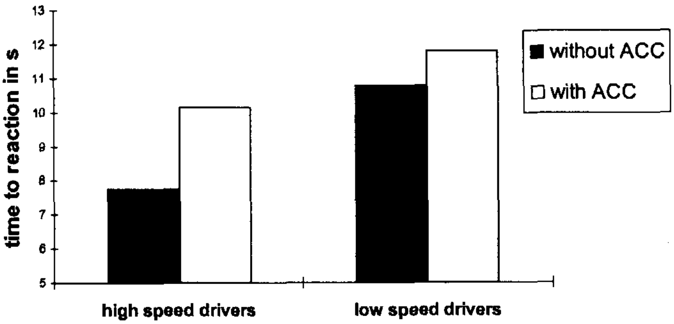

Figure 7-6. The time driver groups waited before they reacted to a car from the right (in seconds). Without ACC this reaction means lifting their foot off the gas pedal, with ACC it means pushing the brake pedal.

7.3.2 Acceptance

The results do not support the hypothesis that driving with an ACC will be appreciated more when driving on the motorway compared to driving on the rural road. Neither on the usefulness scale nor on the comfort scale of the acceptance questionnaire (Van der Laan et al., 1997) was a significant effect of Road type found.

A significant difference was found between the three different time headway conditions of the ACC (1.8 s, 0.6 s and a toggle condition) on the subjective ratings of the comfort and usefulness scales of the acceptance questionnaire (usefulness: $F(2,27)=8.7, p<0.001$, comfort: $F(2,27)=11.4, p<0.001$). This result indicates that all drivers appreciate the toggle ACC the most and the 0.6 s time headway ACC the least. Both average usefulness and comfort scores are shown in figure 7-7.

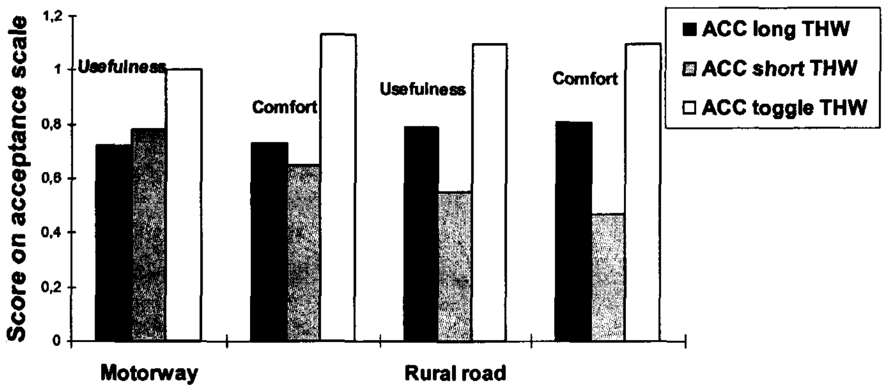

Figure 7-7. Average score on the acceptance questionnaire for the three time headway conditions, on the motorway and on the rural road.

7.3.3 Mental effort

The responses on the Rating Scale Mental Effort (RSME, Zijlstra & Van Doorn, 1985) show that, according to expectation, the participants experienced driving with an ACC as being less effortful than driving without an ACC ($F(1,27)=7.3, p<0.01$). An interaction effect between driving style group and road type ($F(1,27)=5.5, p<0.03$) shows that only the high speed drivers experience driving on the motorway as being less effortful than driving on the rural road. See figure 7-8.

With respect to the different time headway conditions, it was found that the short time headway setting (0.6 s) is experienced as the most effortful of all three time headways settings ($F(2,26)=4.8, p<0.02$).

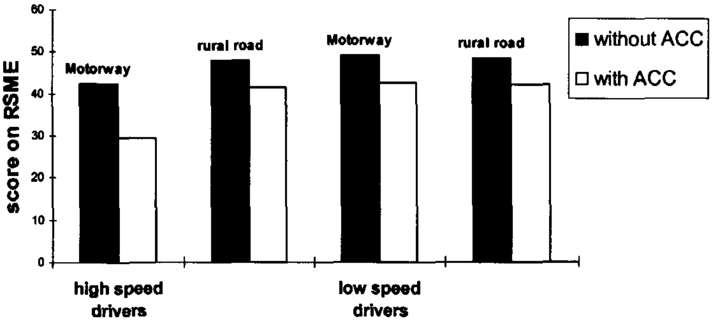

Figure 7-8. Average score on the Rating Scale Mental Effort (RSME) on both types of road.

The heart rate data show the same effect of ACC on mental effort as the subjective data. The 0.10 Hz component is less suppressed during ACC driving compared to driving without ($F(1,24)=3.4, p<0.08$), indicating less invested mental effort when driving with ACC. A main effect of road type ($F(1,24)=4.3, p<0.05$) indicates that drivers invest more mental effort when driving on the motorway, where a main effect of traffic density ($F(1,24)=4.8, p<0.04$) indicates less invested mental effort when they are driving in quiet traffic. Figure 7-9 shows these effects and the expected rest-task difference ($F(1,24)=23.8, p<0.001$).

The subjective difference in mental effort for the three time headway conditions of the ACC is not reflected in the physiological data.

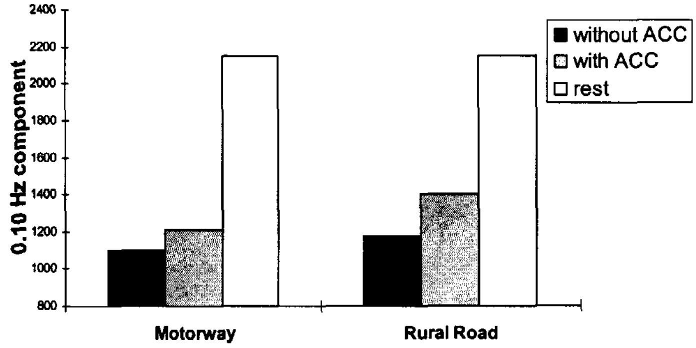

Figure 7-9. Heart rate variability in the 0.10 Hz band on the motorway and the rural road. Average values are shown for driving with and without ACC and during rest measurements.

7.3.4 Activation

The responses on the Bartenwerfer activation scale show that drivers find themselves to be less activated when driving with ACC ($F(1,26)=16.2, p<0.001$). They indicate that their activation is the highest when driving in the short time headway condition (0.6 s) ($F(2,26)=4.7, p<0.02$).

This subjective effect of activation is not reflected in the average heart rate data (i.e. no main effect of ACC and Time headway condition). It was expected that heart rate would be lower when driving with ACC. But figure 7-10 shows that this is only the case on the motorway and in the car following scenario on the rural road. In the other scenarios driving with an ACC leads to an increase of heart rate (interaction ACC*Condition: $F(4,21)=3.3, p<0.03$). Figure 7-10 also shows the rest-task difference ($F(1,26)=6.5, p<0.02$).

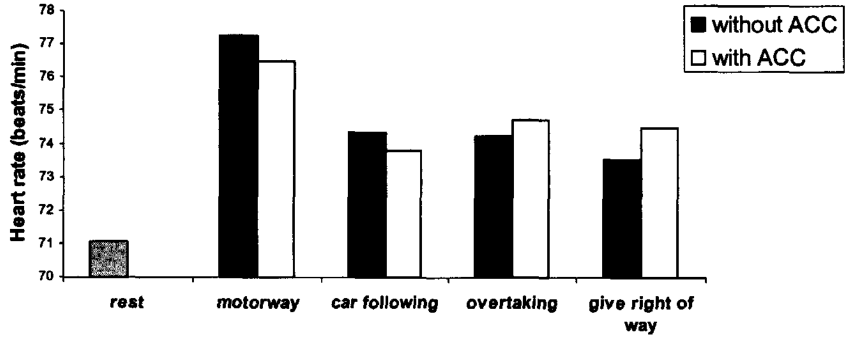

Figure 7-10. Average heart rate with and without ACC, during rest, on the motorway and three specific scenarios on the rural road.

With respect to the three time headway conditions of the ACC, the same effect as in the subjective ratings of activation is found: driving with an ACC with the smallest default time headway of 0.6 s elevates heart rate the most ($F(2,24)=8.0, p<0.002$). As was described above, drivers also indicated on the Bartenwerfer activation scale that their activation was the highest during this condition. Figure 7-11 shows the physiological as well as the subjective effect of activation.

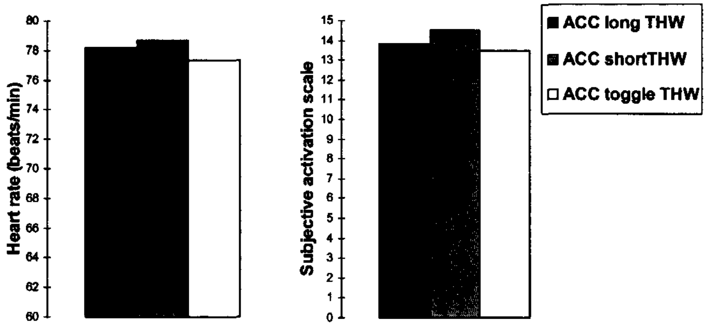

Figure 7-11. The first three bars show the heart rate values. The second three bars show the average score on the Bartenwerfer activation scale. Both indicate the same effect of time headway condition.

7.3.5 Driver group differences

On both types of road a main effect of group was found according to expectation: high speed drivers drive faster than low speed drivers ($F(1,26)=10.0, p<0.004$). See figure 7-3 in section 7.3.1.

When driving on the motorway, it is found that the high speed driver group makes more overtaking manoeuvres ($(1,28)=5.9, p<0.02$). On the rural road the high speed driver group chooses a smaller gap in the opposing traffic when making an overtaking manoeuvre ($F(1,18)=4.4, p<0.05$). When forced to follow a lead car, the high speed driver group shows a smaller time to collision than the low speed driver group ($F(1,24)=64.2, p<0.05$). These results confirm the hypothesised differences in driving style between the two driver groups.

Figure 7-12 shows the differential effect on ACC of the two driving style groups in terms of time to collision (ttc). The minimal measured ttc on the motorway increases when high speed drivers are driving with ACC, but it decreases when low speed drivers are driving with ACC, compared to their minimal ttc when driving without the system (Interaction Group*ACC: $F(1,27)=11.4, p<0.002$).

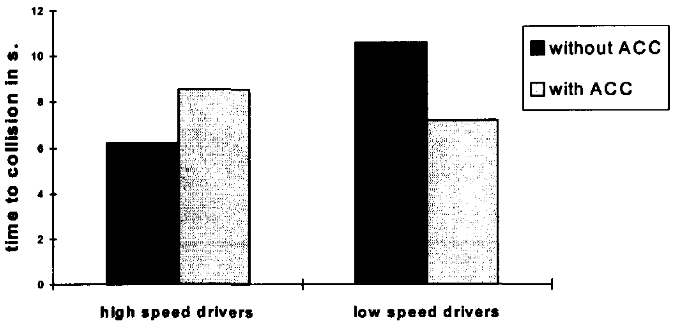

Figure 7-12. Minimal ttc on the motorway for high and low speed drivers, with and without ACC.

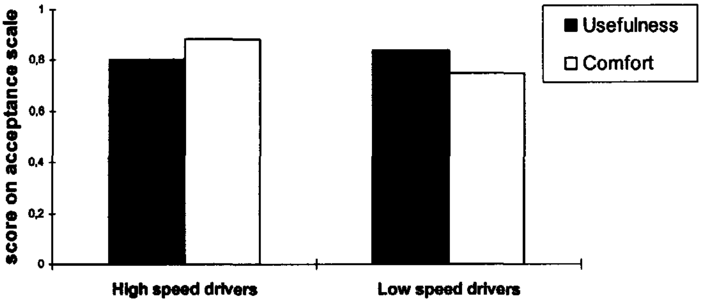

Figure 7-13. Average score on the acceptance questionnaire of the high and low speed driver groups, divided in the subscales usefulness and comfort.

Figure 7-13 indicates that the high and low speed driver groups differ in their appreciation of ACC. The high speed driver group values especially the comfort of the system, the low speed driver group values especially the usefulness of the system ($F(1,28)=2.7, p<0.05$).

No interaction was found between Group and Time headway condition. As was stated in hypothesis no. 7, it was expected that the high speed driver group would appreciate the short time headway condition more and the low speed driver group would appreciate the long time headway condition more. This is not the case. As was stated in section 7.3.2, all drivers, irrespective of their driving style, like the "toggle time headway ACC" the most and the "short time headway ACC" the least.

When looking at their preferred time headway when actually driving in this "toggle ACC", it was found that the minimum time headway was smaller for the high speed driver group during driving in the car following condition on the rural road ($F(1,27)=4.2, p<0.05$). This result indicates that when the driver groups can choose their own time headway, the difference in preference time headway becomes clear: high speed drivers chose the smaller time headway and low speed drivers chose the larger time headway.

7.4 Discussion and conclusions

The main objective of the experiment described in this chapter was to assess effects of Adaptive Cruise Control (ACC) on different types of roads, i.e. motorways and rural roads. Following the set up and the results of the experiment described in chapter 6, effects are described in terms of driving behaviour and acceptance, taking into account different driving styles with respect to speed. Based on these effects implications could be derived for traffic safety for different types of roads and for different drivers.

7.4.1 Driving behaviour with ACC on motorways and rural roads

In the present study driving behaviour with ACC changes according to expectation. The standard deviation of velocity decreases, as well as time headways and time to collisions. Drivers spend more time in the left lane, and they report less mental load when driving with an ACC. Driving speed on the motorway is changed in the opposite direction as expected. In quiet traffic the ACC leads to lower speeds instead of higher speeds. Other research into speed adaptation with ACC is also showing contradictory results. E.g. Hogema & Janssen (1996) and Sayer et al. (1995) found that drivers set a lower speed on their ACC in a driving simulator experiment and an ACC experiment driven in an actual motorway environment respectively. On the other hand for example Ward et al. (1995) found in a field trial that drivers set the ACC at higher speeds compared to driving without.

In the present experiment no effect on speed was found when driving on the rural road. This type of road probably doesn't allow for much speed variation.

Some specific effects for driving with an ACC on the rural road are found that have to do with the specific traffic situations that occur on these types of road. Overtaking another car for example is especially difficult on these roads. Drivers have to estimate a gap in the oncoming traffic that gives them enough time to accelerate and pass the lead car. The present experiment shows that an ACC doesn't help in this difficult situation. On the contrary, overtaking manoeuvres were found to be more dangerous when driving with ACC compared to driving without (i.e. smaller gaps were chosen in opposing traffic). This result can also be interpreted as the overtaking manoeuvre being performed more efficiently with ACC. However, some participants in the experiment experienced how scary the system's automatic reaction can be, when they 'forgot' to overrule the ACC during the overtaking manoeuvre: at the moment they were driving on the opposite lane, trying to pass the car as quickly as possible, the ACC started braking because the time headway with opposite traffic was too small. This warrants the conclusion that overtaking on the rural road is more dangerous with ACC rather than the conclusion that it is more efficient.

Another traffic situation, specific for rural roads, is the intersection where drivers have to give right of way to traffic coming from the right. In this specific situation the ACC has to be overruled because the sensor of the system doesn't look to the right. All participants in the experiment were explicitly told so, which explains the difference that was found in overruling time between motorways and rural roads. Dictated by this traffic situation drivers pressed the brakes more often when driving on the rural road. When comparing this specific situation driven with and without ACC it was found that drivers pressed the brake pedal later in time than that they released their foot off the gas pedal: they react later to traffic from the right when driving with ACC, an effect that could be caused by reduced activation when the longitudinal driving task is taken over by the ACC system.

7.4.2 Acceptance and time headways of ACC

No difference in ACC acceptance was found for the two types of roads. Although average scores on the acceptance questionnaire were somewhat lower than found in the former experiment described in chapter 6, in the current experiment they were also quite positive (close to +1 on the scale -2 to +2). The toggle ACC condition, where drivers can choose between short and long time headway settings, is experienced as the most useful and comfortable. This leads to the conclusion that drivers will probably use ACC's on rural roads just as much as on motorways, especially when it has a driver-selectable headway switch. On rural roads, however, traffic safety is not well served by ACC's, because they lead to very specific problems on these types of roads (as was described in the previous section).

Acceptance of the ACC can also be measured by the amount of overruling by the drivers. When assuming that drivers overrule the system whenever they experience it as not being convenient at that moment, we can infer that on the motorway, in particular, the long time headway of 1.8 s is experienced as being quite inconvenient. Driving in the short time headway of 0.6 s is perceived as the most effortful and the most activating, and the toggle ACC as the least effortful and activating. The toggle ACC probably gives drivers a sense of being in control, which is known to be an important factor in the amount of perceived stress (e.g. Glass & Singer, 1972; Hockey et al., 1989).

7.4.3 Mental effort and activation with ACC's

Driving with an ACC involves less mental effort compared to driving without. This is shown by subjective data as well as by physiological data. Physiological data indicate that driving on the motorway involves more mental effort than driving on the rural road, which is a striking result because one would expect it to be the other way around. The more complicated traffic interactions possible on these types of road, and the larger share of total traffic accidents would suggest that driving on rural roads is more effortful. The higher driving speeds and busy traffic present in the simulator, especially the busy traffic scenarios on the motorway, involve more mental effort. Subjectively, the drivers do not confirm this result. In general, they do not report a perceived difference in mental effort between the two road types. On the contrary, the high speed drivers even report less mental effort on the motorway, which is in line with their underlying needs. That is, driving on the motorway gives them more opportunity to satisfy their need of driving fast. When drivers can drive the way they want they perceive this as being less effortful.

Driving with an ACC decreases perceived activation, as was indicated by the participants. Average heart rate data confirm this result on the motorway and the car following scenario on the rural road. However, specific rural road scenarios like overtaking and giving right of way increase activation (i.e. heart rate). These results point in the direction that these traffic conditions get more difficult when driving with ACC, whereas ACC facilitates driving in traffic scenarios that were already not too complicated: motorway driving and car following; situations in which ACC was originally designed to be used.

With respect to the three time headway settings of the ACC, subjective mental and physiological data do not point in the same direction. Drivers reported to find the 0.6 s ACC time headway the most effortful and activating, while heart rate and heart rate variability show no effect for this type of ACC.

It is not uncommon to find a divergence between subjective and physiological workload indicators elsewhere in the literature (e.g. Veltman & Gaillard, 1993). Janssen et al. (1994) reason that a possible explanation lies in the difference between over-all or peak estimates of subjective and physiological parameters. Subjective ratings of workload might be determined by the worst moment experienced during the test ride (in this case high speeds with very small gaps), while heart rate parameters might more approximate the average workload level. On the other hand, the physiological parameters can be calculated for specific sub-scenarios within one test-ride, like different traffic densities on the motorway, or car-following, overtaking, and giving right of way on the rural road. Subjectively, the results only showed a decrease in perceived mental effort when driving with an ACC. Physiologically, heart rate and heart rate variability showed different effects for these scenarios happening during a test ride. This leads to the conclusion that physiological parameters can provide a more detailed tool to assess a driver's mental load during driving, while subjective indicators give an important overall impression of how driving is experienced.

7.4.4 Driving styles and ACC

In the present experiment the high and low speed driving style groups do not only differ on these self-reported driving styles but also on their driving experience. It turned out that it was not possible to match these two groups on their average kilometres driven per week. Drivers who report to have a high speed driving style, spent significantly more time in their cars than drivers reporting to have a low speed driving style. In the former experiment, described in chapter 6, this relationship was already suspected, but not proved statistically significant. It is concluded that there is a relationship between driving experience and driving style in terms of speed. The theoretical consequence from this finding is that driving styles are not only determined in a top-down way by higher level needs, but also by a bottom-up feedback process resulting from experience with low-level driving tasks.

Driving behaviour results are in line with the self reported differences in driving style. High speed drivers drive faster and make more overtaking manoeuvres compared to low speed drivers. On top of this, driving styles make a difference in how the ACC is appreciated. Low speed drivers emphasise the usefulness of the system in the acceptance questionnaire, whereas high speed drivers emphasise the comfort of the ACC. Both groups have good acceptance of the system, but for different reasons, based on the different needs of the two groups during driving. Low speed drivers have needs in terms of safety. They emphasise the usefulness of ACC because they perceive the system as helpful in their safety need. High speed drivers have needs in terms of expediency and the kick of driving. The ACC's from the experiment do appeal to these needs; they can drive faster with less effort, which is comfortable to them.

In terms of driving behaviour with ACC, the high and low speed groups react differently to driving with the system in terms of time to collision (ttc) on the motorway. Without ACC low speed drivers keep a much larger ttc than do high speed drivers. With ACC, their ttc is decreased, whereas for high speed drivers it is increased. This results in similar ttc's for both groups with ACC, so in the case of adopted following distance, initial differences in driving style are adjusted by influences from the system.

The driving style groups do not differ in their preference for a long or a short time headway. This result confirms the findings of the previous experiment (see chapter 6), where also no effect on ACC time headway preference was found. However, when the drivers in the experiment are forced to follow a lead car on the rural road, the difference between the groups becomes clear. The high speed drivers keep a smaller time to collision than the low speed drivers, which must be a result of the selected time headway setting. This result indicates that a driver selectable headway switch gives in to the preferences of both driving style groups and is therefore the recommended type of ACC.

8. Discussion and conclusions

This chapter discusses the results from all previous chapters. It starts with a brief review of the most important conclusions of the separate studies, which are then translated into short answers to the research questions which were raised in chapter 1. It is concluded that while driving with adaptive cruise control, driver behaviour is changed in a way that is characterised by a more efficient driving style, i.e. higher speeds with smaller deviations, smaller headways, and less reported mental load. On the rural road drivers adapt their behaviour in a way that might not be beneficial for traffic safety, because of dangerous overtaking behaviour and delayed reactions to traffic from the right. Acceptance of adaptive cruise control is high and is influenced by differences in driving style with respect to speed. The acceptance of high speed drivers of ACC is lower than that of low speed drivers, and they prefer the comfort of the system over the usefulness.

After a discussion of the implications from the partner projects, the results are linked to the theoretical issues raised in chapter 3 for more general implications of this thesis. The chapter concludes with implications for further research and general conclusions.

8.1 Overview of results

The preceding empirical chapters discussed a questionnaire study and two experiments in a driving simulator. The questionnaire study focused on drivers' needs and driving styles and the experiments focused on the behavioural reactions and acceptance of driver support systems with respect to these driving styles. This section summarises the results. The next section discusses the general implications in the light of the driver behaviour model that is proposed in chapter 3. After a short discussion of the results from the partner projects, the last section discusses the implications for further research into behavioural aspects of driver support systems.

The questionnaire study described in chapter 5, investigated drivers' needs and driving styles during specific car trips and their judgements of driver support systems. In the model, needs are the higher level goals that drivers try to satisfy, so it is expected that drivers have a higher acceptance of those systems that appeal to their needs. Based on the hierarchical framework of driver behaviour, it was hypothesised that needs are related to driving styles, but that driving styles can be adjusted to satisfy higher level needs. The results show that drivers were positive about the increase of traffic safety by the introduction of driver support systems, but they also report some clearly negative opinions especially regarding giving away the control over the vehicle or being afraid that the car will brake at dangerous moments. The majority of drivers ranked safety as their most important need during a trip. Driving relaxed was also considered to be important, whereas expediency and the kick of driving were considered to be mostly unimportant. The study has shown that, as was predicted from the hierarchical driver behaviour framework, a relationship exists between needs and some of the self reported driving styles. It is concluded that needs and driving styles can be seen as stable traits that can be different between drivers but not between trips. That is, drivers don't change their needs and accompanying driving styles when going on different trips like commuter or holiday trips.

The experiment described in chapter 6 was aimed at the assessment of driver response to Adaptive Cruise Control systems, as a function of driving style. The four groups of drivers taking part in the study differed on reported driving styles concerning Speed (driving fast) and Focus (the ability to ignore distractions), of which Speed was a good predictor of actual driving behaviour. The driving style Focus did not show any effect on actual driving behaviour as measured in the simulator. The results show effects on driving behaviour with an ACC in terms of higher speed, smaller minimum time headway and larger brake force. Interaction effects between driving style and behaviour with and without ACC were found on minimum time headway and maximum braking level when drivers had to perform an emergency stop with an ACC. Low speed drivers increase their braking force in this situation much more when driving with an ACC than high speed drivers. Furthermore, minimum time headway adopted by low speed drivers decreased much more with an ACC than it did for the high speed drivers. In their acceptance of ACC the driving style groups differed as well. Only high speed drivers do not appreciate the non-overrulable versions of the ACC, whereas low speed drivers perceive both versions as comfortable and useful.

The main objective of the experiment described in chapter 7 was to assess effects of Adaptive Cruise Control (ACC) on driving behaviour on different roads, i.e. motorways and rural roads. Again taking into account the driving style of drivers. The results of the experiment show driving behaviour reactions according to expectation; smaller standard deviation of velocity, more driving in the left lane, and less reported mental load when driving with an ACC compared to driving without. Driving with an ACC decreases perceived activation, and average heart rate data confirm this result on the motorway and the car following scenarios on the rural road. However, specific rural road scenarios like overtaking and giving right of way increase physiological activation. The results also show that there is no difference in acceptance of ACC's on the two different road types. But in line with the results of the former experiment, driving styles make an important difference in how the ACC is appreciated. Low speed drivers indicate to like the usefulness of the system, whereas high speed drivers emphasise the comfort of the ACC. Both groups have a good acceptance of the system, but for different reasons, which clearly have their background in the different needs of the two groups. All drivers, irrespective of their driving style, appreciate the toggle ACC the most, where they can choose between long and short headway settings. In terms of driving behaviour, the results show that driving with an ACC on the rural road leads to dangerous overtaking behaviour and delayed reactions to traffic from the right. The conclusion from these findings is that we should be careful with the introduction of ACC's to road types other than the motorway. Drivers will probably use their ACC equally often on both rural roads and on motorways, because of the high acceptance, but behavioural adaptation may seriously deteriorate traffic safety, particularly on the rural road.

8.1.1 Answers to the research questions

Based on this overview of results, we can shortly answer the main research questions that were posed in chapter 1. Given that the experiments were focused on one particular type of driver support systems, namely adaptive cruise control, the questions are answered for this particular kind of system.

What are the effects of Adaptive Cruise Control systems on driving behaviour?

On motorways drivers are going to adopt higher speeds with smaller variations, smaller time headways to the vehicle in front, and they will be driving more often on the left lane when driving with ACC. Merging manoeuvres are carried out faster, pulling in to a smaller gap between cars on the other lane. In addition, drivers experience less mental load when driving with ACC compared to driving without. In economical terms, these changes in driving behaviour on the motorway can be characterised by a more efficient driving style; but traffic safety might not be served very well: higher speeds and smaller headways are factors known to increase accident likelihood.

For specific rural road traffic conditions, driving behaviour with ACC will surely not increase traffic safety. Driving with ACC is found to lead to dangerous overtaking behaviour and delayed reactions to traffic from the right.

To what extent will Adaptive Cruise Control systems be accepted by drivers?

Acceptance of ACC was found to be high. Both experiments showed positive comfort and usefulness ratings. Time headway settings of the ACC did not influence drivers' acceptance, but overrulability clearly did: acceptance of a non-overrulable ACC system was lower. In a non-overrulable ACC the driver is no longer in control of driving (except when the system is turned off), and being in control is known to be an important factor in the amount of perceived stress. This also explains why driver acceptance increased when they were in control of setting the ACC time headway by means of a driver selectable headway switch.

To what extent will driving behaviour and acceptance be determined by individual differences in driving style?

Acceptance of ACC is particularly influenced by individual differences, specifically in the driving style with respect to speed. The acceptance of high speed drivers of ACC is lower, and what they prefer is the comfort of the system over the usefulness. High speed drivers stressing the system's comfort means that they evaluate it in terms of pleasant, nice, likeable etc., and not so much in terms of effective, assisting and good (i.e. useful). These acceptance differences apparently originate from differences in higher order needs of these drivers (see also section 8.3).

In some respects driving behaviour with ACC is influenced by individual differences in driving style. Time headway and time to collision are influenced such that use of ACC removes the initial differences in driving style between the groups. In other words: driving with ACC harmonises traffic, which could lead to an increase of traffic efficiency and to a reduction of the number of accidents (see also Brookhuis & De Waard, in press).

8.2 Implications from partner projects

This PhD project was part of the research programme "Technology Assessment Automatic Vehicle Guidance". Three other partner PhD projects participated in this programme, each focusing on different aspects of the introduction of driver support systems to road traffic. This section will shortly discuss the most important results from these partner projects and the implications in the light of the results that were presented in this thesis.

Policy making and societal consequences

The project focusing on policy making and societal consequences, used the Delphi method for identifying future markets for driver support systems, barriers for further developments and policy measures to overcome these barriers (Marchau & van der Heijden, 1997). With regard to the introduction of driver support systems, the study confirms that the implementation can be seen as an evolutionary process. In the short term (before 2005), various warning devices for driving support will enter the market, next to vehicle following systems with limited deceleration capabilities. No serious technical obstacles seem to prevent manufacturers from implementing these systems in the near future. In the mid term (2005-2020), the introduction of more advanced systems that temporarily control the vehicle in case of dangerous situations or support the driver in keeping his/her lane, is overall considered to be somewhat uncertain. Most uncertain seems to be the implementation of the autopilot. In another study (Marchau et al., 1999), attractiveness of driver support systems has been measured using conjoint analysis techniques. Both drivers and fleet-owners of cars, trucks and buses were questioned about their preferences regarding several alternatives. The results indicate some acceptance of new driver support systems and drivers especially prefer warning devices for lane keeping and changing over no support or steering assistance.

Traffic flow

The project that investigated the impacts of driver support systems on traffic flow and safety, used a micro-simulation model to study the effects of the new traffic participants (Minderhoud, 1999). Three bottleneck situations have been selected as test cases for the impact assessment, since it was assumed that impacts might differ by location. Also, five ACC configurations, differing in headway setting, speed range, acceleration range, and reactivation functionality were used. The general conclusion from this project is that ACC can have a positive impact on motorway capacity. Requirements to attain these gains in capacity are a headway setting below 1.2 s that cannot be adjusted by the driver. The ACC should also be reactivated automatically after it has been overruled by the driver. The supported speed range should be large for safety considerations (including stop-and-go speeds and the safe approach of standing queues). There is little evidence that this speed range has a substantial impact on the capacity (Minderhoud, 1999).

Legal aspects

The project that investigated legal aspects of driver support systems, focused on vehicle safety standards and liability issues (Van Wees, 1999). Changing existing vehicle safety standards may be needed to guarantee the safety of driver support system technology or to eliminate obstacles for introduction (driver support systems may be in conflict with existing standards as far as their constructional or operational characteristics do not comply with these standards). This is primarily the responsibility of the European Community.

One of the most important liability issues is that of product liability. Product liability, i.e. liability for defective products, is often regarded as a possible constraint for the rapid deployment of driver support systems. (Perceived) product liability risks may slow down developments or even outweigh the benefits of marketing such systems.

It is emphasised that it will be impossible for producers to avoid all liability claims. Manufacturers are liable if a product does not provide the safety that a person is entitled to expect. As far as this is the result of production defects this liability can be called strict. However, with regard to design or presentation defects product liability must rather be regarded a liability based on negligence. There are some specific aspects that in particular will influence the level of product liability standards. Such circumstances are the fact that these systems are used in road traffic and therefore safety defects can easily lead to serious accidents and the fact these products will be used by a great diversity of drivers, including less capable and less careful persons.

Integration

These results from the partner projects relate to the results described in this thesis in a number of ways. Firstly the Delphi study showed that adaptive cruise control is expected on the market very soon. The simulator experiments in this thesis also focused on this system, as well as the "traffic flow partner project". The results from this latter study show that adaptive cruise control can have a positive effect on traffic flow as long as the driver is not able to influence the preset headway. In other words, this project recommends to take the driver out of the control loop with respect to headway control. However, taking the driver out of the control loop could be problematic when a situation is encountered that the system cannot handle. These potential effects also relate to the analysis of the legal aspects of driver support systems. For instance, the question whether or not product liability will be an impediment for rapid deployment of driver support systems is heavily influenced by the uncertainties about the potential safety effects of driver support systems.

When comparing the recommended headway setting of less than 1.2 s with the preferences of the drivers in this thesis, we can conclude that a short headway shouldn't be a problem in their acceptance of ACC. From a legal point of view, however, liability for inadequate warnings or technical failures, which are more likely with short headways, may prevent manufacturers from producing short headway ACC's. The finding that non-overrulable ACC's are in conflict with existing standards supports the view expressed in this thesis that they are not a very likely candidate for future ACC systems.

8.3 General implications

8.3.1 Needs and driving styles

In chapter 3 a hierarchical framework of driving behaviour was proposed, where driving is characterised as goal-directed behaviour aiming to satisfy individual needs placed at the highest level in the hierarchy. This goal directed nature of driving is characterised by a set of higher level needs that affects the way in which the set of observable low level driving tasks is performed. Strategies at the strategical level of driving are translated into driving styles at the tactical level. At this tactical level priorities are selected and subtasks from the operational lower level are co-ordinated. The levels communicate by means of intermediate mental models, which provide information of performing a particular driving task. The introduction of adaptive cruise control does not alter these relationships; it merely introduces an extra mental model associated with the task that the ACC supports, i.e. speed and headway control. In this study the framework is used as a tool to predict and interpret the effects of needs, driving styles and driving behaviour to driving with an ACC. Although the framework is very general, it has offered a useful means to generate hypotheses for the questionnaire and the experimental studies. The framework formed the theoretical basis for categorising the participants of the experimental studies into 'driving style groups'. The questionnaire study confirmed the relationship between global needs and driving styles, as proposed by the framework. Therefore, driving style can be understood in terms of a driver's higher order needs. This means that the driving styles that were chosen as a selection criterion in the driving simulator experiments, i.e. high and low speed and high and low focus (the ability to ignore distractions), can be seen as a result of a driver's needs in terms of safety, expediency, and the kick of driving. More specifically, the results of the questionnaire study showed that drivers with a high speed driving style (tactical level) have needs in terms of expediency and the kick of driving, and drivers with a low speed driving style try to satisfy needs like safety and driving relaxed. Drivers with a high focus driving style also value safety high, whereas drivers with a low focus driving style are again more inclined to the kick of driving.

The experiments in the driving simulator clearly demonstrate the relationship between driving style in terms of speed and the operational level driving behaviour. In the framework, the task scheduler assigns which low level driving tasks are performed, given a certain driving style. In the case of a high speed driving style, this turns out to be a higher velocity, a smaller time headway, more driving on the left lane on the motorway and more overtaking manoeuvres. The driving style factor Focus does not show any effects in low level driving behaviour as measured in the simulator. It was expected that a high focus driving style would lead to a better lane position with smaller deviations from that lane position. Also, performing a secondary task while driving was expected to distract the low focus drivers more than high focus drivers, but this was not the case.

It is concluded that it is very difficult to validate the driving style questionnaire factor Focus with actual driving behaviour in the simulator. At least in this study no observable differences were found. But also West, who developed the original questionnaire, did not find a validation of the factor Focus (personal communication). The driving style factor, referring to the ability to ignore distractions, remains an interesting driving quality, when studying traffic safety in general or the effects of driver support systems, which take the driver out of the loop and thereby change the role of the driver in terms of attention needed for the driving task. Therefore, it would be interesting to explore the role of this driving style in more detail in further research.

In contrast with the focus driving style, self-reported differences in speed driving style turn out to be a good predictor of actual driving behaviour in the simulator. Also West et al. (1992), on whose questionnaire the one used in this study was based, found in a validation study that self-reports of the driving style speed correlated highly with observer ratings of speed in real traffic. They concluded that self-reports of driving style are reasonably valid reflections of actual behaviour.

8.3.2 Driver groups and ACC

The main reason to discriminate between driving style groups in the simulator experiments on ACC was that the theoretical framework of driver behaviour predicted that behavioural reactions to driver support systems would be different between drivers with different needs. Driving style determines how operational subtasks are scheduled and attention is managed, and therefore when and how an ACC system is used to take over the car-following subtask.

The experiments did find these different behavioural reactions to ACC, but not very often. When interaction effects are found between driving style and reaction to ACC, they level out the initial differences in driving style between the groups. The first experiment, for example, shows that low speed drivers increased their maximum braking level when they had to perform an emergency stop with ACC much more than the high speed drivers did. Without ACC high speed drivers already have to brake much harder in this situation than low speed drivers, but because of their increased braking level with ACC, group differences are almost gone. The same levelling-effect is shown in both experiments on time headway and time to collision. Without ACC low speed drivers keep a much larger distance to the car in front than the high speed drivers. In the first experiment all drivers decrease their headway when driving with ACC, but this decrease is much larger for the low speed drivers. In the second experiment high speed drivers even increase their time to collision, whereas low speed drivers decrease it when driving with ACC.

The result in both experiments is the same: initial differences in distance to the car in front disappear when driving with ACC. It is concluded that individual differences in headway keeping are being overruled by influences from the environment or momentary circumstances, in this case being the Adaptive Cruise Control system. This is to be expected because the ACC actually takes over the headway keeping task, leaving no room for individual differences. Although it was shown in the former section that individual differences in driving behaviour (speed, headway, etc.) can be understood in terms of more general applicable traits (in the hierarchical framework of driver behaviour: their needs), in specific situations like driving with an ACC, driving behaviour is better described by reference to this situation.

In their acceptance or appreciation of the ACC the driver groups differ as well, although the two experiments show slightly different results here. The first experiment on the motorway shows that high speed drivers are less positive about a non-overrulable ACC with respect to both perceived comfort and perceived usefulness. The second experiment on two road types shows that slow speed drivers indicate to like the usefulness of the system, whereas high speed drivers stress the comfort of the ACC. Both results can be explained in the light of the hierarchical framework of driver behaviour. Usefulness and comfort are subjective labels based on evaluation of predictions of the ACC mental model. Feedback to strategical level needs influences whether using the ACC makes the overall driving task performance satisfying. In the case of a non-overrulable ACC, where both usefulness and comfort are rated lower by the high speed driver groups, this indicates that their need of kick of driving is frustrated with this system. Their 'kick of driving' comes from their control over the car, which is taken away in the non-overrulable ACC. The ACC systems from the second experiment apparently do appeal to one of those needs; they can drive faster with less effort, which is very comfortable for them. Remember that the results also showed that this is the only group that experiences driving on the motorway as being less effortful. This indicates again that they can satisfy their expediency need on this type of road. When drivers can drive the way they want they perceive this as being less effortful. Low speed drivers have needs more in terms of safety. They emphasise the usefulness of ACC because they perceive the system as helpful in their safety need. Comfort is not that important to them and therefore they do not value this aspect of an ACC as much as the high speed drivers do. This result can be used in terms of marketing strategies. High and low speed drivers should be addressed differently, i.e. for high speed drivers the comfort of the systems should be emphasised and for low speed drivers the usefulness in terms of a safety enhancing system.

8.4 Further research

In the discussion of results and their implications, a couple of interesting issues arise that need further research.

Firstly, there is the issue of the driving style Focus, or the ability to ignore distractions. As was concluded above, this study did not find any observable differences in driving behaviour for this driving style factor, but driver support systems can change the role of the driver in terms of attention needed for the driving task. It would therefore be

interesting to further explore individual differences in attention management in combination with driver support systems that might take the driver out of the loop.
Secondly, an important issue would be the driver's mental model of the intelligent system(s) with which they are driving. In the current study mental models were important mediators in the proposed framework of driver behaviour but they were not, as such, research subjects in this thesis. In critical situations in particular, numerous examples from pilots in air traffic indicate the importance of mental models and the predictions about system performance that are based on these mental models. Proper reactions of drivers of automated systems in critical situations depend for a large part on their proper mental model. Further research into the construction of mental models and their usefulness in critical situations is recommended. This is a type of experiment for which the driving simulator would be an ideal instrument because of its possibility of creating the same critical driving situations without actually harming the driver.

8.5 A vision on the future

Getting almost at the end of this thesis, it might be interesting to have a look at what our future road transport system. Based on the current state of affairs and the results of the research project "Technology Assessment Automatic Vehicle Guidance", two scenarios are described, in which the development of ACC's each goes a different way.

The first scenario is one in which it seems not very likely that ACC's will ever be used on a large scale in the future. The main reason for this is the big uncertainty on how the technology will develop that is needed for a safe functioning of driver support systems. Especially the technological development of sensors, which are needed for the distance keeping performed by an ACC, seems to be a problem. When driving in real traffic, problems with the sensor arise on curved roads (front sensors do not look around the corner), in detecting full speed ranges of the vehicle in front (from stationary to very fast driving), and in bad weather conditions. Technology and acceptance by the driver are very closely connected. For drivers it is very important to experience the technology working perfectly, because only the perceived advantages of driving with an ACC will lead them to accept and trust the system (see also chapter 3). "Perfect" technology is also needed to prevent system failure (e.g. it does not "see" another vehicle and collides with the car in front driving on the preset speed), and thereby prevent serious accidents. It seems very uncertain when or whether this perfect technology will be available in the near future.
Another problem with the introduction of ACC's in road traffic is that different manufacturers will bring different ACC's on the market in terms of preset headway and deceleration capacity. Only European rules and standards can prescribe what should be the legally adopted headway and other safety standards. It seems highly unlikely that such standards will be introduced before the first ACC's enter the market.

On top of this, product liability risks may slow down developments or even outweigh the benefits of marketing such systems (Van Wees, 1999).
Several road users equipped with different systems, in combination with non-ACC drivers, will probably result in highly unpredictable car-following behaviour on the roads. A well-known example is a car taking over another car. At the moment of merging in front of the car, the headway of the following car is suddenly decreased. When this car is driving with an ACC system it will decelerate at its maximum capacity (depending on the manufacturer of the system) in order to regain the preset headway. When this car is driving manually, the driver will probably accept this shortened headway for a moment, knowing that the car in front drives faster and that the headway will be increased soon. The example points to a problem that might never be overcome by a technical system, namely it does not possess a deeper insight in traffic.

The second scenario is one in which most cars will be driving around with ACC or similar systems within 15 years. The main assumption we have to make for this future scenario is that the technological development will progress and that the available ACC's will be "fail-safe". The ACC's don't have to be perfect. Even if they do not look around the corner or fail to detect a full speed range, drivers might accept the systems as they are, and experience some comfort and usefulness in the more restricted systems (as was shown in this study). Also other mechanisms play an important part in the use of ACC systems. It might become a gadget that everyone likes to have in his car (like the air-conditioning and air bags since a couple of years ago). Also politics can play an important role. When these systems are seen as a solution for the present congestion problems (which are only expected to grow in the next years), the government might stimulate ACC use, and thereby boost the penetration rate of these systems in the vehicle fleet. This policy requires subsidies or other financial offers to increase the deployment rate of longitudinal assistance systems. According to Minderhoud (1999) will more advanced ACC systems result in capacity gains up to 25%. But the design of the system dictates the possible capacity gains. When boundaries of e.g. headway settings are defined at an early stage in collaboration with the system manufacturers, an increase in roadway capacity and safety seems likely. But only if a critical mass of drivers actually uses the system. This study shows that acceptance doesn't seem to be a big problem, especially acceptance of those systems that leave the driver enough freedom. In this scenario use of ACC systems works as a kind of "self-fulfilling prophecy". The more drivers will use the system, the more it will meet the expectancies of an increase in comfort, road capacity, and traffic safety. This will again lead more people to switch to ACC driving.

8.6 Conclusions

This thesis shows that Adaptive Cruise Control seems to be a promising new technology in traffic. That is, under certain conditions and limitations.

In the first place, the experiments clearly demonstrated that driving behaviour with ACC leads to positive effects in terms of traffic efficiency. Driving with ACC reduces speed variability and initial individual differences in driving behaviour on two-lane motorways, which harmonises traffic. On top of this, acceptance results indicate that the headway adopted by the ACC does not influence the preferences of drivers. Even very short headways (0.6 – 1.0 s), which are shown to increase motorway capacity by Minderhoud (1999), are accepted very well.
Secondly, a more harmonised traffic pattern can also reduce the number of accidents and thereby increase traffic safety. In addition to increasing traffic efficiency ACC's could therefore also increase traffic safety.

The distinction between high and low speed drivers was found to be important in the acceptances of ACC. Both driver groups like driving with an ACC, but for different reasons. High speed drivers like the comfort of the system, whereas low speed drivers like the system's usefulness. As described above, this finding could be used in marketing strategies in order to get both driver groups into ACC-cars. Most popular in this respect is the ACC where drivers can change their headway setting during driving, i.e. switch between short and longer headways depending on their personal preferences and the current situation. However, when drivers with such a selectable headway switch choose to drive with a headway setting of more than 1.2 s (which they regularly do), the predicted gain in motorway capacity disappears (Minderhoud, 1999). This illustrates the conflict between a driver's need to be in control and the predicted gain in motorway capacity when headway control is taken away. The headway setting of future ACC's should therefore depend on the most important goal that is to be achieved with the system. When the emphasis is on increasing driver comfort (more appealing to high speed drivers) the ACC should be equipped with a driver selectable headway switch ranging from 0.6 to 2.0 s. When the emphasis is on increasing motorway capacity, the ACC should have a fixed headway of 1.2 s or less.

With regard to the effects on traffic safety caution is appropriate.
On motorways the measured higher speeds and smaller headways with ACC are factors known to increase accident likelihood. The importance of speed as a contributory factor to accident liability cannot be overstated; faster drivers are relatively unsafe drivers (French et al, 1993). The categorisation of high and low speed drivers in looking at traffic safety aspects is therefore an important one. Several studies found a consistent link between self-reported driving speed and accident rates (Wilson & Greensmith, 1983, French et al., 1993). The fact that ACC does not decrease driving speed of high speed drivers, on the contrary, the first experiment shows that it may

*in*crease their driving speed, must therefore be taken as a serious threat for traffic safety.

On roads other than motorways, we should be very careful with the introduction of ACC. Driving behaviour as well as heart rate results indicated that, with respect to traffic safety in specific situations on rural roads, ACC might not serve us particularly well. Dangerous overtaking behaviour and delayed reactions to traffic from the right were found in combination with an elevated heart rate. This clearly indicates that these traffic scenarios get more difficult when driving with ACC, whereas ACC facilitates driving in traffic conditions that were already not too complicated: motorway driving and car following-situations where ACC was originally designed to be used.

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Summary

Introduction

During past decades Western society has been increasingly confronted by problems in traffic and transport. Road transport is growing too fast and this has negative repercussions on energy, emissions, traffic safety and road capacity (congestion). Driver support technologies are regarded as a promising tool for improving road network traffic performance and safety. These driver support systems are defined as systems in which the driving task of a driver is partly or entirely taken over by an automated system. Such automation of driver tasks might improve traffic safety and driver comfort, increase road capacity or limit energy consumption and emissions.

The first generation of driver support systems will become available on the European within a few years. These early driver assistance systems, denoted with Adaptive Cruise Control (ACC), can replace the speed adaptation and distance keeping task of the driver with respect to the vehicle in front on the same lane. Vehicles equipped with an ACC can drive on the current motorways between non-equipped vehicles. Infrastructural adaptations are not required.

Research questions and study approach

The extent to which driver support systems realise their goals of increasing traffic safety and efficiency will depend, among other things, on how they affect driving behaviour and how many people are willing to drive with such systems. Individual driver needs and driving styles are therefore the starting point in this research. It is expected that whenever driver support systems frustrate these needs and driving styles, acceptance of the systems is low and unwanted or even dangerous reactions of drivers may occur.

The main research questions are:

1. What are the effects of driver support systems on driving behaviour?
2. To what extent will driver support systems be accepted by individual drivers?
3. To what extent will driving behaviour and acceptance be determined by individual differences?

In order to answer these questions a literature study was carried out into existing driver behaviour models to assess the factors that play a part in driver behaviour. It also outlines what are the most important implications of those models for the implementation of driver support systems. Subsequently a questionnaire study was performed among Dutch car drivers about their judgements on several driver support systems, and their needs and driving styles during different kinds of trip. After that two experiments were performed in the driving simulator at the Centre for Environmental and Traffic Psychology (COV), in which the effects of different forms of an ACC were tested with groups of subjects who differed in their reported driving styles. The most import results and conclusions will be discussed in the next sections.

Literature study

Chapter 3 of this thesis describes a literature study into psychological models of driver behaviour. These models are placed within the hierarchical structure of driving tasks as proposed by Michon (1971, 1985) and Janssen (1979). These are the motivational models at the *strategical* level, in which the goals and needs of drivers, like expediency, safety, risk, and comfort, play an important role. At the next *tactical* level, the main issue of driver behaviour models is the actual mental model drivers have of the current traffic situation, their vehicle, and their own state. At the third *operational* level the driver behaviour models have to do with attention allocation over different sub-tasks and the workload that is associated with driving under different conditions and in different situations.

An integrated hierarchical framework of driver behaviour is proposed that is structured along the three different driver behaviour levels and carries aspects of most of the theoretical models that were discussed. Cognitive constructs such as driver needs are connected to the low-level operational driving task. The framework illustrates the assumption that a driver's needs are related – via strategy selection and attention management – to the driver tasks at the operational level. An Adaptive Cruise Control system takes over tasks at this operational level. Performance related information is communicated back to the strategical level, where needs represented by global goals (e.g. expediency) and constraining factors (e.g. risk avoidance) determine whether the driver is satisfied with the way the supported driving progresses. If the driver is not satisfied, he/she may change his/her driving strategy, resulting in a change of driving style, chosen route or even disabling the ACC system.

The research described in this thesis uses the hierarchical framework of driver behaviour as a tool to make predictions about needs, driving styles and driving behaviour reaction to driving with an adaptive cruise control system. It is expected, for example, that high speed drivers will have lower acceptance of an ACC and, where the system permits it, will overrule the ACC more than low speed drivers will. The reason for this is that an ACC system does not correspond to the needs of the high speed driving drivers. When driving an ACC that cannot be overruled the high speed drivers will have an even lower acceptance because the system is more restrictive.

Questionnaire study

The questionnaire study, described in chapter 5, investigated drivers' judgements of different driver support systems and their needs and driving styles during different kinds of trips. All three aspects (judgements, needs and driving styles) are considered important for the future developments of driver support systems.

The results of the questionnaire show that the respondents see both positive and negative aspects to the four driver support systems. About 50% of the respondents indicates that traffic safety will increase when driver support systems are introduced. Respondents were negative about having taken over control of driving by a system. As was predicted from hierarchical framework of driver behaviour, the results show a relationship between needs and some of the self reported driving styles. Needs and driving styles can be seen as stable traits that can be different between drivers but not very much between trips. That is, drivers don't change their needs and accompanying driving styles when going on different trips like commuter or holiday trips.

This conclusion is used in the experimental studies described in the following chapters. An important selection criterion for the subjects participating in the experiments was their self-reported driving style. This gives the opportunity to predict their behaviour and reactions to driving with driver support systems, because we can expect this to be in line with their higher level needs.

Driving simulator experiment on Adaptive Cruise Control (ACC)

In this first driving simulator experiment, described in chapter 6, four groups of driver participants, who differed on reported driving styles concerning Speed (high speed = driving fast) and Focus (high focus = the ability to ignore distractions), drove the same motorway route in the driving simulator with and without an ACC system. It was expected that especially these driving styles are important in a driver's reaction to ACC, because of the reduced control drivers will have on speed, and the enhanced susceptibility to distractions when using the system, which will create safety hazards. In the experiment different hypotheses were tested with respect to driving style groups and their reactions to driving with an ACC.

The results show that the driving style Speed was a good predictor of actual driving behaviour, whereas the driving style Focus did not show any effect on actual driving behaviour as measured in the simulator. In general all drivers adapted their behaviour according to expectation, irrespective of their predetermined driving style. They are going to drive faster, with a smaller minimum time headway when driving with an ACC. Also merging manoeuvres were carried out more efficiently. Interaction effects between driving style and behaviour with and without ACC were found on minimum time headway and maximum braking level when drivers had to perform an emergency stop with an ACC. Low speed drivers increase their braking force in this situation much more when driving with an ACC than high speed drivers. Furthermore, minimum time headway adopted by low speed drivers decreased much more with an ACC than it did for the high speed drivers. In their acceptance of ACC the driving style groups differed as well. Only high speed drivers do not appreciate the non-overrulable versions of the ACC, whereas low speed drivers perceive both versions as comfortable and useful.

In the light of the higher speeds, smaller time headways and more efficient merging manoeuvres that were found when participants drove with ACC, the system seems a promising development in terms of traffic efficiency. However, the higher speeds and smaller headways that were found when driving with an ACC, might point to possible negative effects on traffic safety.

Driving simulator experiment on ACC on different road types

In this second driving simulator experiment, described in chapter 7, two groups of drivers, who differed with respect to reported driving style in terms of speed, drove on a motorway and on a rural road route in the driving simulator. They drove the same routes with a normal car and with an ACC system with adjustable headway settings. In this study hypotheses were tested with respect to Adaptive Cruise Control (ACC) use on two types of roads: motorways and rural roads.

The results show, among other things, that driving with an ACC decreases perceived activation. Average heart rate data confirm this result on the motorway and the car following scenarios on the rural road. However, specific rural road scenarios like overtaking and giving right of way increase physiological activation.
Differences in acceptance of ACC's on the two different road types are not found. But in line with the results of the former experiment, driving styles make an important difference in how the ACC is appreciated. Low speed drivers indicate to like the usefulness of the system, whereas high speed drivers emphasise the comfort of the ACC. Both groups have a good acceptance of the system, but for different reasons, which clearly have their background in the different needs of the two groups. All drivers, irrespective of their driving style, appreciate the toggle ACC the most, where they can choose between long and short headway settings. In terms of driving behaviour, the results show that driving with an ACC on the rural road leads to dangerous overtaking behaviour and delayed reactions to traffic from the right.

The conclusion from these findings is that we should be careful with the introduction of ACC's to road types other than the motorway. Drivers will probably use their ACC equally often on both rural roads and on motorways, because of the high acceptance, but behavioural adaptation may seriously deteriorate traffic safety, particularly on the rural road.

General conclusions and implications

This thesis shows that Adaptive Cruise Control seems to be a promising new technology in traffic. That is, under certain conditions and limitations.
In the first place, the experiments clearly demonstrated that driving behaviour with ACC leads to positive effects in terms of traffic efficiency. Driving with ACC reduces speed variability and initial individual differences in driving behaviour on motorways, which harmonises traffic. On top of this, acceptance results indicate that the headway adopted by the ACC does not influence the preferences of drivers. Even very short headways (0.6 – 1.0 s), which are shown to increase motorway capacity by Minderhoud (1999), are accepted very well.
Secondly, a more harmonised traffic pattern can also reduce the number of accidents and thereby increase traffic safety. In addition to increasing traffic efficiency ACC's could therefore also increase traffic safety.

The distinction between high and low speed drivers was found to be important in the acceptances of ACC. Both driver groups like driving with an ACC, but for different reasons. High speed drivers like the comfort of the system, whereas low speed drivers like the system's usefulness. As described above, this finding could be used in marketing strategies in order to get both driver groups into ACC-cars. Most popular in this respect is the ACC where drivers can change their headway setting during driving, i.e. switch between short and longer headways depending on their personal preferences and the current situation. However, when drivers with such a selectable headway switch choose to drive with a headway setting of more than 1.2 s (which they regularly do), the predicted gain in motorway capacity disappears (Minderhoud, 1999). This illustrates the conflict between a driver's need to be in control and the predicted gain in motorway capacity when headway control is taken away. The headway setting of future ACC's should therefore depend on the most important goal that is to be achieved with the system. When the emphasis is on increasing driver comfort (more appealing to high speed drivers) the ACC should be equipped with a driver selectable headway switch ranging from 0.6 to 2.0 s. When the emphasis is on increasing motorway capacity, the ACC should have a fixed headway of 1.2 s or less.

With regard to the effects on traffic safety caution is appropriate.
On motorways the measured higher speeds and smaller headways with ACC are factors known to increase accident likelihood. The importance of speed as a contributory factor to accident liability cannot be overstated; faster drivers are relatively unsafe drivers (French et al, 1993). The categorisation of high and low speed drivers in looking at traffic safety aspects is therefore an important one. Several studies found a consistent link between self-reported driving speed and accident rates (Wilson & Greensmith, 1983, French et al., 1993). The fact that ACC does not decrease driving speed of high speed drivers, on the contrary, the first experiment shows that it may *in*crease their driving speed, must therefore be taken as a serious threat for traffic safety.
On roads other than motorways, we should be very careful with the introduction of ACC. Driving behaviour as well as heart rate results indicated that, with respect to traffic safety in specific situations on rural roads, ACC might not serve us particularly well. Dangerous overtaking behaviour and delayed reactions to traffic from the right were found in combination with an elevated heart rate. This clearly indicates that these traffic scenarios get more difficult when driving with ACC, whereas ACC facilitates driving in traffic conditions that were already not too complicated: motorway driving and car following-situations where ACC was originally designed to be used.

Samenvatting

Inleiding

De afgelopen decennia is de westerse samenleving geconfronteerd met een sterk groeiend wegverkeer. Nadelige gevolgen zijn te merken in de totale CO2 uitstoot, wegcapaciteit (files) en veiligheid. De toepassing van nieuwe, bestuurdersondersteunende technologieën in het wegverkeer wordt gezien als een mogelijkheid om verkeersveiligheid en wegcapaciteit te vergroten. Deze bestuurdersondersteunende systemen worden gedefinieerd als systemen die de rijtaak geheel of gedeeltelijk overnemen van de bestuurder. Een dergelijke automatisering zou, behalve verkeersveiligheid en wegcapaciteit, ook het comfort van de bestuurder kunnen vergroten en de schadelijke uitstoot van CO2 kunnen verminderen.

De eerste generatie van deze bestuurdersondersteunende systemen komt binnenkort op de Europese markt. Deze systemen worden aangeduid met de term Adaptive Cruise Control (ACC). Ze kunnen automatisch de snelheid van het voertuig aanpassen om zodoende een gewenste veilige afstand te kunnen handhaven ten opzichte van de voorligger op dezelfde strook. Voertuigen die zijn uitgerust met zo'n systeem kunnen gewoon op bestaande autosnelwegen rijden tussen voertuigen die niet zijn voorzien van dit systeem. Het gebruik van ACC vereist geen infrastructurele aanpassingen aan de wegen.

Onderzoeksvragen - en opzet

ACC leidt niet automatisch tot een verhoging van capaciteit, veiligheid en bestuurderscomfort. Dat hangt onder andere af van de effecten van deze systemen op het rijgedrag van bestuurders en de hoeveelheid mensen die bereid zijn met zo'n systeem te gaan rijden (acceptatie). Rijgedrag en acceptatie van ACC zijn onderwerp van dit onderzoek. De verschillende behoeften en rijstijlen van bestuurders zijn daarbij het uitgangspunt. De verwachting is namelijk dat de acceptatie laag zal zijn wanneer bestuurdersondersteunende systemen deze behoeften en rijstijlen frustreren. Er kunnen zelfs niet bedoelde of gevaarlijke gedragsreacties zullen optreden.
De belangrijkste onderzoeksvragen zijn:

1. Wat zijn de effecten van bestuurdersondersteunende systemen op het rijgedrag?
2. In hoeverre worden deze systemen geaccepteerd door bestuurders?
3. In hoeverre worden rijgedrag en acceptatie bepaald door individuele verschillen in behoeften en rijstijlen?

Om deze onderzoeksvragen te kunnen beantwoorden is eerst een literatuurstudie gedaan naar verschillende psychologische modellen van de bestuurder, om inzicht te krijgen in de factoren die een rol spelen in zijn gedrag. Daarna is een vragenlijstonderzoek uitgevoerd onder leden van de ANWB naar hun mening over verschillende bestuurdersondersteunende systemen en hun behoeften en rijstijlen tijdens verschillende soorten ritten. Hierna zijn twee experimenten uitgevoerd in de rijsimulator van het Centrum voor Omgevings- en Verkeerspsychologie (COV) in Groningen. Hierin zijn verwachtingen getoetst omtrent de gedragsreacties van bestuurders met verschillende rijstijlen, wanneer zij rijden met een ACC systeem.
De belangrijkste bevindingen van deze onderzoeksdelen worden hieronder besproken.

Literatuurstudie

Hoofdstuk 3 van dit proefschrift beschrijft een literatuurstudie naar psychologische modellen van bestuurdersgedrag. Deze modellen worden elk onder gebracht op één van de drie niveaus van de bestuurderstaak, zoals voorgesteld door Michon (1971, 1985) en Janssen (1979). Op het *strategische* niveau zijn dit de motivationele modellen, waarin de doelen en behoeften van bestuurders, zoals snelheid, risico en comfort, een belangrijke rol spelen. Op het *tactische* niveau gaan de modellen over het actuele mentale model dat bestuurders hebben van de verkeerssituatie, hun voertuig en hun eigen toestand. Op het derde, *operationele* niveau bevinden zich de modellen die te maken hebben met de verdeling van aandacht over de verschillende rijtaken en de werkbelasting die samenhangt met rijden onder verschillende omstandigheden.

Op basis van deze modellen is een hiërarchisch model geconstrueerd dat de aanname illustreert hoe de behoeften van een bestuurder – via strategie selectie – zijn gerelateerd aan de basis-rijtaken op het laagste, operationele niveau. Een ACC neemt taken van de bestuurder over op dit operationele niveau. Er is feedback naar het strategische niveau, waar behoeften bepalen of de bestuurder tevreden is met het rijden met de ACC. Deze behoeften worden gerepresenteerd door algemene doelen (zoals snelheid) en beperkende factoren (zoals het vermijden van risico), Is de bestuurder niet tevreden dan kan hij/zij de gekozen strategie aanpassen, hetgeen een verandering in rijstijl, gekozen route, of zelfs het uitschakelen van het ACC systeem tot gevolg heeft.

Dit zogenaamde "hierarchical framework of driver behaviour" wordt in de rest van dit proefschrift gebruikt om voorspellingen te doen over de behoeften van bestuurders, hun rijstijlen en daadwerkelijk rijgedrag met een ACC systeem. Een hypothese op basis van dit model is bijvoorbeeld dat bestuurders met een snelle rijstijl een lagere acceptatie zullen hebben van een ACC dan bestuurders met een langzamere rijstijl. Zij zullen zoveel mogelijk proberen in te grijpen in het systeem. De reden hiervoor is dat een ACC systeem niet overeenkomt met de behoeften van de snellere rijders, en de verwachting is dat zij in het evaluatie-proces dan ook niet tevreden zijn met de werking van het systeem.

Vragenlijst-onderzoek

In het vragenlijstonderzoek, beschreven in hoofdstuk 5 van dit proefschrift, werden drie aspecten onderzocht waarvan verwacht werd dat ze belangrijk zijn voor de toekomstige ontwikkeling van bestuurdersondersteunende systemen. Deze drie aspecten zijn (1) de mening van bestuurders over verschillende toekomstige systemen, (2) de behoeften van bestuurders wanneer zij verschillende ritten maken, en (3) de rijstijlen van bestuurders tijdens deze ritten.

De resultaten laten zien dat de groep respondenten evenveel positieve als negatieve aspecten toeschrijft aan de vier gevraagde systemen. Zo denkt ongeveer 50 % dat de verkeersveiligheid zal toenemen, maar ook 50 % geeft aan niet graag de controle over het autorijden uit handen te geven. Zoals voorspeld op basis van het "hierarchical framework of driver behaviour" laten de resultaten een relatie zien tussen de behoeften van bestuurders en sommige van hun gerapporteerde rijstijlen. Behoeften en rijstijlen kunnen worden gezien als stabiele eigenschappen van een bestuurder, die niet afhankelijk zijn van het soort rit (zoals woon-werk verkeer of een lange rit voor vakantie-doeleinden).

Deze conclusies worden gebruikt in de experimenten die zijn uitgevoerd in de rijsimulator. Daar worden namelijk de gerapporteerde rijstijlen gebruikt als belangrijk selectie-criterium voor de proefpersonen. Dit geeft de mogelijkheid om hun gedrag en reacties op de ACC systemen te kunnen voorspellen, omdat deze afgeleid zijn van hun algemene behoeften.

Rijsimulator-experiment met Adaptive Cruise Control (ACC)

In dit eerste rijsimulator-experiment, beschreven in hoofdstuk 6, reden vier groepen deelnemers zonder en met een aantal ACC systemen steeds eenzelfde route over een 2-baans autoweg. De vier groepen verschilden in hun rijstijlen met betrekking tot snelheid en focus (in hoeverre is men in staat om afleidingen te negeren). De verwachting was dat met name deze rijstijlen belangrijk zijn in de reactie van een bestuurder op een ACC, omdat dit systeem de bestuurder minder vrijheid laat in zijn snelheid, en doordat de aandacht en attentie wordt beïnvloed als rijtaken worden overgenomen. In dit experiment werden verschillende hypothesen getoetst met betrekking tot de verschillende rijstijl-groepen en hun reacties op het rijden met een ACC.

De resultaten laten zien dat de zelfgerapporteerde rijstijl “snelheid” een goede voorspeller is voor het daadwerkelijke rijgedrag in de simulator. Bestuurders met een hoge of lage focus-rijstijl daarentegen verschilden niet in hun gemeten rijgedrag. In het algemeen pasten alle bestuurders hun rijgedrag aan volgens verwachting, onafhankelijk van hun vooraf vastgestelde rijstijl. Zij gaan sneller rijden en met een kleinere afstand tot hun voorligger dan wanneer zij zonder ACC rijden. Ook werden invoeg-manoeuvres efficiënter uitgevoerd. Interactie effecten van rijstijl-groep en gedrag met of zonder ACC werden gevonden tijdens een file-situatie waarin plotseling geremd moest worden. De langzamere rijders moeten in deze situatie hun rempedaal veel verder intrappen met een ACC dan de snellere rijders. Ook neemt hun afstand tot de voorligger veel meer af dan die van de snelle rijders. Ook met betrekking tot acceptatie verschilden de rijstijl-groepen. Opvallend was dat alleen de snelle rijders een lagere acceptatie hadden van de ACC systemen waarbij de bestuurder zelf niet meer kon ingrijpen (de zogenaamde non-overrulable systemen), terwijl de langzamere rijders beide versies (wel- en niet overrulable) even comfortabel en nuttig vonden.

In het algemeen lijkt ACC een veelbelovend systeem lijkt voor het verbeteren van de wegcapaciteit, gezien de hogere snelheden, kortere volgtijden en efficiëntere invoeg-manoeuvres. De gevonden hogere snelheden en kleinere volgafstanden wijzen echter op mogelijke negatieve gevolgen voor de verkeersveiligheid.

Rijsimulator-experiment met ACC op verschillende wegtypen

In dit tweede rijsimulator-experiment, beschreven in hoofdstuk 7 van dit proefschrift, reden snelle en langzamere rijders op een twee-baans snelweg en een 80 km/uur weg. Zij reden allen dezelfde route zonder en met een ACC systeem dat was voorzien van een knop waarmee bestuurders zelf hun volgafstand konden instellen. In dit experiment werden vooral hypothesen getoetst met betrekking tot het gebruik van en rijgedrag met een ACC op deze twee wegtypen.

De resultaten laten onder andere zien dat de subjectieve mentale belasting en waargenomen activatie lager zijn wanneer men met een ACC rijdt dan zonder ACC. De hartslagdata bevestigen dit resultaat op de snelweg en een volg-situatie op de 80 km/uur weg. Andere specifieke situaties op dit soort wegen, zoals inhalen en het voorrang geven aan verkeer van rechts, laten juist een toename van fysiologische activatie zien.
Verschillen in acceptatie op de twee wegtypen zijn niet gevonden. Maar, de verschillende rijstijlen bepalen wel in hoeverre de ACC wordt geaccepteerd. Dit is in overeenstemming met de resultaten van het vorige experiment. Langzamere rijders geven in dit experiment aan dat zij vooral het nut inzien van het systeem, terwijl snelle rijders vooral het comfort benadrukken. Beide groepen hebben dus een hoge acceptatie van de ACC, maar om verschillende redenen, die duidelijk hun achtergrond hebben in de verschillende behoeften van deze twee groepen bestuurders. Alle deelnemers, onafhankelijk van hun rijstijl, waardeerden die ACC het meest, waar zij zelf tijdens het rijden hun volgafstand konden aanpassen. In termen van rijgedrag laten de resultaten vooral zien dat het rijden met een ACC op 80 km/uur wegen leidt tot gevaarlijk inhaalgedrag en vertraagde reacties op voorgaand verkeer van rechts.

Er wordt geconcludeerd dat we erg voorzichtig moeten zijn met de invoering van ACC systemen op andere wegtypen dan de snelweg. Omdat de acceptatie van ACC op beide wegen niet uitmaakt, zullen bestuurders het systeem waarschijnlijk even vaak gebruiken op 80 km/uur wegen als snelwegen. Maar gedragsveranderingen kunnen de verkeersveiligheid op deze 80 km/uur wegen serieus in gevaar brengen.

Algemene conclusies en implicaties

In het algemeen laat dit proefschrift zien dat, onder bepaalde voorwaarden en beperkingen, ACC een veelbelovende technologie lijkt te zijn.
In de eerste plaats laten de experimenten zien dat rijgedrag met een ACC tot positieve effecten leidt met betrekking tot verkeers-efficiëntie. Het rijden met een ACC vermindert onder andere de variabiliteit in snelheid en de initiële verschillen in rijstijl met betrekking tot snel en langzamer rijden op de snelweg. Dit leidt tot een harmonisering van het wegverkeer. Daarnaast blijkt de ingestelde volgafstand van de ACC geen invloed te hebben op de acceptatie van het systeem. Zelfs korte volgafstanden van 0.6 tot 1.0 s, waarvan Minderhoud (1999) heeft aangetoond dat ze duidelijk de wegcapaciteit vergroten, worden zeer goed geaccepteerd.
In de derde plaats kan een meer geharmoniseerd verkeerspatroon leiden tot de afname van ongelukken en de verkeersveiligheid dus bevorderen.

Ook wordt geconcludeerd dat het onderscheid tussen snelle en langzame rijders belangrijk is, vooral in de acceptatie van ACC. Beide bestuurdersgroepen waarderen de ACC, maar om verschillende redenen. Snelle rijders waarderen het comfort, terwijl langzamere rijders meer het nut waarderen. Dit resultaat zou gebruikt kunnen worden in marketing-strategieën om beide groepen bestuurders over te halen een ACC in hun auto aan te schaffen. Het meest populair is hierbij de knop waarmee bestuurders zelf hun volgafstand kunnen regelen en aanpassen aan hun persoonlijke preferenties en de verkeerssituatie van dat moment. Alleen wanneer bestuurders met deze knop een volgafstand zouden kiezen die groter is dan 1.2 s (hetgeen regelmatig gebeurt), zal de voorspelde winst in wegcapaciteit verdwijnen (Minderhoud, 1999). Dit illustreert het conflict tussen de behoefte van een bestuurder om zoveel mogelijk controle te houden over zijn/haar rijtaak, en de voorspelde winst in wegcapaciteit wanneer deze eigen controle wordt weggenomen. De ingestelde volgafstanden van toekomstige ACC systemen zouden daarom ook afhankelijk moeten zijn van het meest belangrijke doel dat men er mee wil bereiken. Is dit doel het comfort van de bestuurder (hetgeen de snellere rijders meer aanspreekt) dan zou een ACC uitgerust moeten worden met een zelf-instelbare volgafstand tussen de 0.6 en 2.0 s. Wanneer de nadruk meer ligt op het vergroten van de wegcapaciteit (en dus het verminderen van de files), dan zou een ACC systeem een vast ingestelde volgtijd moeten hebben van 1.2 s of minder.

Met betrekking tot de effecten op de verkeersveiligheid moeten de conclusies toch wat voorzichtiger zijn. De gereden hogere snelheden en kleinere volgafstanden met een ACC op de snelweg zijn factoren die bekend staan de kans op ongelukken te verhogen. De invloed van snelheid op ongelukken moet niet onderschat worden; snelle rijders zijn relatief onveilige rijders. De indeling in snelle en langzamere rijders is dus, zeker in termen van verkeersveiligheid, een belangrijke. Verschillende onderzoeken hebben aangetoond dat er een consistent verband is tussen zelf-gerapporteerde snelheid en ongeluks-percentages. Het feit dat ACC de snelheid van snelle rijders niet naar beneden brengt, maar juist, zoals het eerste experiment aantoont, verhoogt, moet daarom worden gezien als een serieuze bedreiging voor de verkeersveiligheid.
Daarnaast moeten we op andere wegen dan snelwegen oppassen met de introductie van ACC. Zowel rijgedrag als hartslag resultaten laten zien dat de verkeersveiligheid afneemt in specifieke situaties op de 80 km/uur weg. Gevaarlijk inhaalgedrag en vertraagde reacties op verkeer van rechts zijn gevonden in combinatie met een verhoogde hartslag. Dit toont duidelijk aan dat deze verkeerssituaties juist moeilijker worden wanneer ze met een ACC gereden worden, terwijl de ACC alleen het rijden vergemakkelijkt in situaties die toch al niet zo gecompliceerd waren: het rijden op de snelweg en in volg-situaties. Maar daar was ACC dan ook oorspronkelijk voor bedoeld.

Appendix A

Toelichting voor het invullen van deze enquête

Wij zijn geïnteresseerd in aspecten van het autorijden die ú belangrijk vindt en in uw werkelijke rijstijl in bepaalde verkeerssituaties. ***Dit staat geheel los van de officiële verkeers- en gedragsregels.***

Het invullen van deze enquete duurt ongeveer 10 minuten. Leest u eerst steeds nauwkeurig de vraag en de wijze waarop deze beantwoord moet worden. Er zijn geen goede of foute antwoorden: ***het gaat om úw situatie en úw mening.***

Wij benadrukken dat de door u verstrekte gegevens vertrouwelijk worden verwerkt en dat anonimiteit is gegarandeerd. Bij de verwerking van uw enquête gegevens heeft de TU Delft alleen uw ANWB lidmaatschapsnummer. De ANWB heeft zelf geen toegang tot uw persoonlijke enquête gegevens. Dit betekent dat uw identiteit en uw persoonlijke enquête gegevens altijd strikt gescheiden blijven.

U kunt de ingevulde enquête aan ons terugsturen (het liefst zo spoedig mogelijk) door gebruik te maken van de bijgevoegde antwoordenveloppe. Hierop hoeft géén postzegel te worden geplakt.

Enquête: algemene gegevens

1. **Bent u een man of een vrouw?** ○ Man
   (aankruisen wat van toepassing is) ○ Vrouw

2. **Wat is uw leeftijd?** .... jaar

3. **Hoe lang bezit u uw rijbewijs al?** .... jaar

4. **Hoeveel kilometers rijdt u gemiddeld per week?** .... km

Automatische Voertuig Besturing

De volgende vragen gaan over een aantal mogelijke Automatische Voertuig Besturings toepassingen. Wilt u bij elk uw mening geven.

1. Een *'signaal'-systeem* waarschuwt u door middel van piepsignalen en/of rode licht signalen op uw dashboard, wanneer u een voertuig of een ander obstakel op de weg te snel nadert. Het spoort u dus aan om te gaan remmen.

   Het voordeel van dit systeem lijkt me (kruis eventueel meerdere opties aan):
   ☐ dat de veiligheid zou toenemen
   ☐ dat ik een extra prikkel krijg om mijn rijgedrag aan te passen
   ☐ dat ik minder hoef op te letten
   ☐ dat ik minder risico loop om te botsen
   ☐ Anders, namelijk: ....
   ☐ Geen mening.

   Het nadeel van dit systeem lijkt me (kruis eventueel meerdere opties aan):
   ☐ dat de veiligheid zou afnemen
   ☐ dat mijn aandacht voor het verkeer zou kunnen verslappen
   ☐ dat zo'n systeem mij irriteert
   ☐ dat het in sommige situaties niet goed zal werken
   ☐ dat het tot schrikreacties leidt bij mijn achterliggers
   ☐ Anders, namelijk: ....
   ☐ Geen mening.

2. Een *'Anti-Bots' systeem,* grijpt automatisch in door te gaan remmen, wanneer u een voertuig of een ander obstakel op de weg te snel nadert.

   Het voordeel van zo'n systeem lijkt me (kruis eventueel meerdere opties aan):
   ☐ dat de veiligheid zou toenemen
   ☐ dat ik minder hoef op te letten
   ☐ dat ik minder risico loop om te botsen
   ☐ Anders, namelijk: ....
   ☐ Geen mening.

   Het nadeel van zo'n systeem lijkt me (kruis eventueel meerdere opties aan):
   ☐ dat de veiligheid zou afnemen
   ☐ dat mijn aandacht voor het verkeer zou kunnen verslappen
   ☐ dat ik zelf geen controle meer heb over de auto
   ☐ dat wordt afgeremd op een moment dat het gevaarlijk is (bijv. file rijden)
   ☐ dat wordt geremd op een moment dat het niet nodig is
   ☐ Anders, namelijk: ....
   ☐ Geen mening.

3. Een *'Intelligent Cruise Control' systeem* houdt uw auto met een vaste snelheid op een vaste, veilige afstand van een eventuele voorligger. Wanneer uw voorligger langzamer rijdt dan u of plotseling gaat remmen, zal dit systeem, door automatisch het gas los te laten en te gaan remmen, uw auto steeds op deze veilige afstand houden. De consequentie is dat uw auto langzamer gaat rijden of zelf(s) stil gaat staan.

Het voordeel van zo'n systeem lijkt me (kruis eventueel meerdere opties aan):
☐ dat ik energie-zuinig rijdt
☐ dat de doorstroming van het verkeer beter wordt
☐ dat het veiliger wordt op de weg
☐ Anders, namelijk: ....
☐ Geen mening.

Het nadeel van zo'n systeem lijkt me (kruis eventueel meerdere opties aan):
☐ dat ik zelf geen controle meer heb over de auto
☐ dat het minder veilig wordt op de weg
☐ dat ik niet snel kan rijden
☐ dat de volgafstand anders wordt dan ik wil
☐ dat een ander het gat tussen mij en de voorligger opvult en mijn auto plotseling sterk reageert
☐ Anders, namelijk: ....
☐ Geen mening.

4. Een aparte *'AVB-rijstrook'* op de snelweg is een aparte baan waar automatisch auto's achter elkaar rijden. Wanneer u op een AVB strook gaat rijden, kunt u met constante snelheid vlak achter uw voorligger aan rijden. U kunt nu zelf niets meer doen, behalve aangeven dat u op bepaalde vaste punten weer van deze rijstrook af wilt.

Het voordeel van zo'n systeem lijkt me (kruis eventueel meerdere opties aan):
☐ dat ik altijd met een constante snelheid rijd
☐ dat ik minder hoef op te letten
☐ dat ik energie-zuinig rijd
☐ dat de doorstroming van het verkeer beter wordt
☐ Anders, namelijk: ....
☐ Geen mening.

Het nadeel van zo'n systeem lijkt me (kruis eventueel meerdere opties aan):
☐ dat ik zelf geen controle meer heb over de auto
☐ dat autorijden niet meer leuk is
☐ dat het minder veilig wordt op de weg
☐ dat het in- en uitvoegen lastiger wordt
☐ Anders, namelijk: ....
☐ Geen mening.

5. **Zou u volgend jaar mee willen doen aan een vervolgonderzoek, waarin verdere praktische toepassingen van AVB worden getest?**

☐ Ja, ☞ Vul uw ANWB lidmaatschapsnummer in: ... - .... - .... - ....
☐ Nee, (☞ Wilt u alstublieft wel de rest van deze enquête invullen)

Lange Autoritten

De vragen gaan over de situatie waarin u een **lange autorit** maakt. Hiermee wordt bedoeld: **langer dan 150 km** en géén woon-werk verkeer. Denkt u hierbij aan een vakantierit.
Als u nooit zo'n autorit maakt kunt u deze vragen overslaan.

Stelt u zich bij het maken van deze vragen de laatste keer voor dat u zo'n lange autorit maakte.

1. **Hoe vaak komen deze ritten in uw geval voor?**
(Aankruisen wat van toepassing is)
○ Zelden
○ Soms
○ Vaak

2. **Wanneer was de laatste keer dat u zo'n lange autorit maakte?**
(Aankruisen wat van toepassing is)
○ Afgelopen week
○ Langer dan een week geleden
○ Langer dan een maand geleden

3. **Rijdt u tijdens deze ritten meestal alleen of samen met anderen?**
(Aankruisen wat van toepassing is)
○ Alleen
○ Samen met anderen

4. **Kunt u van elk van de onderstaande punten in volgorde aangeven, hoe belangrijk u ze vindt.** (1 = belangrijkste t/m 7 = onbelangrijkste). De volgorde is onafhankelijk van of dat nu daadwerkelijk mogelijk is tijdens deze lange ritten. Lees eerst alle mogelijkheden en vul dan pas uw cijfers in. In elk hokje moet dus een ander cijfer komen te staan.

	Volgorde van belangrijkheid
- **Genieten van de omgeving**	...
- **De eigen snelheid kunnen bepalen**	...
- **Ontspannen rijden**	...
- **Veilig rijden**	...
- **Snel rijden**	...
- **De kick van het rijden zelf**	...
- **Het kunnen doen van andere activiteiten tijdens het rijden** (bijvoorbeeld het luisteren naar de radio of praten met medepassagiers)	...

Wilt u van elk van de volgende vragen aangeven hoe vaak het op u van toepassing is tijdens het autorijden? (Aankruisen wat van toepassing is)

Lange Autoritten	(bijna) nooit	zelden	soms	vaak	(bijna) altijd
1. Rijdt u snel?	○	○	○	○	○
2. Past u uw snelheid aan aan de snelheid van uw voorligger?	○	○	○	○	○
3. Rijdt u voorzichtig?	○	○	○	○	○
4. Rijdt u gejaagd?	○	○	○	○	○
5. Rijdt u wel eens harder dan 120 km/uur **op de snelweg**?	○	○	○	○	○
6. Gaat u harder rijden als gevolg van druk van andere automobilisten?	○	○	○	○	○
7. Haalt u wel eens rechts in (afgezien van op- en afritten)?	○	○	○	○	○
8. Negeert u passagiers die u aansporen uw snelheid te veranderen?	○	○	○	○	○
9. Rijdt u zoveel mogelijk op dezelfde rijstrook?	○	○	○	○	○
10. Rijdt u wel eens door rood licht?	○	○	○	○	○
11. Rijdt u wel eens harder dan 50 km/uur **binnen de bebouwde kom**?	○	○	○	○	○
12. Neemt u wel eens voorrang wanneer u dat niet heeft?	○	○	○	○	○
13. Blijft u kalm wanneer dingen erg snel/onverwacht gebeuren?	○	○	○	○	○
14. Vindt u het gemakkelijk om afleiding (zoals dingen die aan de kant van de weg gebeuren) te negeren tijdens het rijden?	○	○	○	○	○
15. Houdt u zoveel mogelijk ruim afstand ten opzichte van uw voorligger?	○	○	○	○	○
16. Wisselt u vaak van rijstrook?	○	○	○	○	○
17. Voegt u kort in voor degene die u inhaalt?	○	○	○	○	○
18. Overtreedt u wel eens de snelheidslimiet op **80 km/uur wegen**?	○	○	○	○	○

Appendix B

Acceptatie-lijst

Zojuist heeft u gereden met een bepaalde uitvoering van een 'Intelligente Cruise Control'. Wilt u hieronder aangeven wat u van het systeem vond tijdens het rijden?

Er zijn telkens 5 antwoordmogelijkheden. Als u een term perfect van toepassing vindt, zet dan een kruisje in het vakje dat het dichtst bij die term staat. Als u een term in zekere mate van toepassing vindt zet dan aan die kant, dus links of rechts van het middelste vakje, een kruisje. Als u er geen uitgesproken mening over hebt, zet dan een kruisje in het midden.

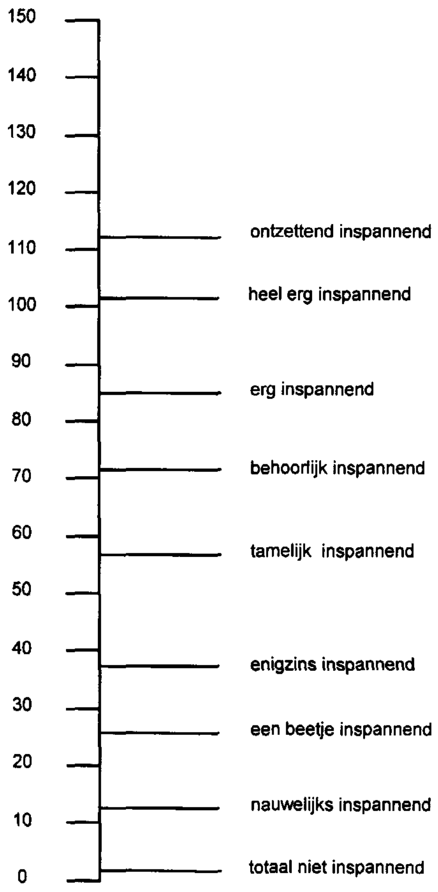
Ik vond dit 'Intelligente Cruise Control' systeem tijdens het rijden:

nuttig	☐	☐	☐	☐	☐	zinloos
plezierig	☐	☐	☐	☐	☐	onplezierig
slecht	☐	☐	☐	☐	☐	goed
leuk	☐	☐	☐	☐	☐	vervelend
effectief	☐	☐	☐	☐	☐	niet effectief
irritant	☐	☐	☐	☐	☐	aangenaam
behulpzaam	☐	☐	☐	☐	☐	waardeloos
ongewenst	☐	☐	☐	☐	☐	gewenst
waakzaamheidverhogend	☐	☐	☐	☐	☐	slaapverwekkend

Appendix C

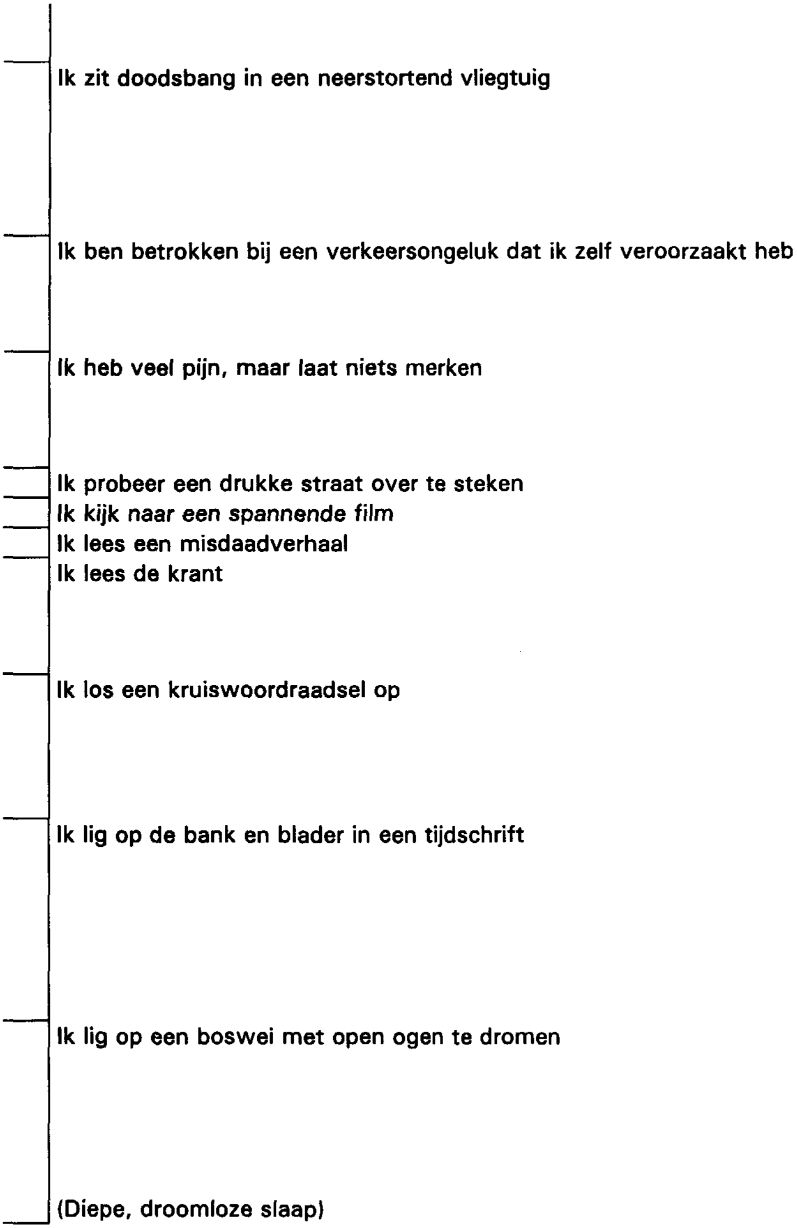
Beoordelingsschaal Mentale Inspanning BSMI

Wilt u door middel van het zetten van een kruisje bij onderstaande lijn aangeven hoeveel inspanning het u heeft gekost om deze taak (welke u zo even heeft verricht) te verrichten.



Appendix D

Beoordelingsschaal Mentale Activatie



Ik zit doodsbang in een neerstortend vliegtuig

Ik ben betrokken bij een verkeersongeluk dat ik zelf veroorzaakt heb

Ik heb veel pijn, maar laat niets merken

Ik probeer een drukke straat over te steken
Ik kijk naar een spannende film
Ik lees een misdaadverhaal
Ik lees de krant

Ik los een kruiswoordraadsel op

Ik lig op de bank en blader in een tijdschrift

Ik lig op een boswei met open ogen te dromen

(Diepe, droomloze slaap)

Appendix E

Opinions on driver support systems

Obstacle Detection System:

Positive aspects	
Increase of traffic safety	60%
Urges on changing behaviour	46%
Less attention to pay to traffic	5%
Less risk to collide	42%

Negative aspects	
Decrease of traffic safety	5%
Decreases attention	44%
System is irritating	41%
System can break down	39%
System leads to shock reactions	25%

Collision Avoidance Systeem:

Positive aspects	
Increase of traffic safety	42%
Less attention to pay to traffic	7%
Less risk to collide	58%

Negative aspects	
Decrease of traffic safety	12%
Decreases attention	32%
Takes over control	65%
Brakes at dangerous moments	51%
Brakes at unnecessary moments	43%

Adaptive Cruise Control:

Positive aspects	
Increase of traffic safety	45%
Improves traffic flow	47%
Saves energy	30%

Negative aspects	
Decrease of traffic safety	9%
Takes over control	56%
Impossible to drive fast	15%
Unwanted headway	27%
Brakes at dangerous moments	70%

Automated Highway System:

Expected positive aspects	
Always constant speed	40%
Less attention to pay to traffic	21%
Improves traffic flow	65%
Saves energy	43%

Negative aspects	
Decrease of traffic safety	5%
Takes over control	56%
Takes away the fun of driving	39%
Difficulties merging in and out	43%

About the author

Marika Hoedemaeker was born in 1968 in Jakarta, Indonesia. When she was 2,5 years old she came back to live in the Netherlands. She obtained her degree in Experimental Psychology at the University of Groningen in 1994. Her master's thesis focused on divided and sustained attention problems of patients with chronic very severe concussions. The patients were tested by means of a driving simulator test at the Rehabilitation Centre Heliomare, Wijk aan Zee.

After finishing the study, she went to the Delft University of Technology to join the department of Work and Organizational Psychology as a PhD student. During this research, she has presented various papers on international conferences and in The Netherlands. Marika has published articles of her work in several scientific and professional journals. For two years she was a member of the Works Council of the Faculty of Technology and Society and chairwoman of the PhD-council of the research school TRAIL. At the end of 1998 she worked at Nissan Cambridge Basic Research, USA, as a guest researcher for two months.

At present she works as a researcher at TNO Human Factors institute in Soesterberg.

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