DRIVER SUPPORT IN CONGESTION

AN ASSESSMENT OF USER NEEDS AND IMPACTS ON DRIVER AND TRAFFIC FLOW

Cornelie van Driel

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Contents

Chapter 1

Introduction

High expectations rest on in-vehicle technology aiming at a safer, more efficient and cleaner transport system. This thesis presents the so-called Congestion Assistant – based on observed user needs – that can improve traffic efficiency and traffic safety during congested traffic situations on motorways. This first chapter describes the background of this research and its objectives and scope. In addition, the research approach and a summary of the scientific and practical relevance are presented.

1.1 Background

Mobility is a key factor for modern societies. However, it also brings about problems, such as congestion, accidents and pollution (European Commission, 2006). In Europe, congestion affects about 10% of the major road network daily and costs an estimated €50 billion per year. And although traffic safety has improved recently, around 1.4 million accidents still occur on the European roads every year, which cost an estimated €200 billion per year. Furthermore, it is acknowledged that road transport has an adverse impact on the environment. It accounts for about 20% of the greenhouse gas emissions in Europe by generating roughly 800 million tonnes of CO_2 equivalents each year. According to the European Commission, more than 90% of the road accidents are partly caused by human errors, such as distraction and fatigue (European Commission, 2002). Moreover, large reaction times and little anticipation behaviour of drivers can lead to unstable traffic flows and result in traffic jams. Together with non-optimal driving behaviour, congestion induces up to 50% of the fuel consumption (European Commission, 2006).

High expectations rest on in-vehicle systems to contribute to solving these problems (European Commission, 2002; Ministry of Transport, 2004). These systems use advanced information and communication technology to assist the driver with his driving task. It is expected that these so-called driver support systems can compensate for the unfavourable human behaviour that causes accidents, congestion and pollution. To meet these expectations, insight is needed into the impacts of such systems on the driver and the traffic flow. Research is conducted to study, for example, to what extent driving behaviour changes when drivers make use of in-vehicle systems and how this affects the performance of the traffic flow. Recently, the effects of two systems on driver acceptance and driving behaviour were examined in a field operational test with twenty equipped vehicles in the Netherlands (Transport Research Centre, 2006). The systems included Adaptive Cruise Control (ACC) that supports the driver in keeping a proper distance to the vehicle ahead and Lane Departure Warning (LDW) that warns the driver when he unintentionally leaves the lane. The participants were positive about the systems, particularly about ACC. Furthermore, the results on driving behaviour showed indications for an enhanced traffic safety: larger following distances, better use of indicators and less unintended lane departures.

Most driver support systems are not on the market yet. Research into these systems concentrates on their potential impacts on the driver and the traffic flow by using simulation facilities, such as driving simulators and traffic simulation models. Hegeman et al. (2007) studied the functioning and acceptance of an Overtaking Assistant in a driving simulator experiment. They concluded that the design of the system could be improved to better suit the driver's preferences. By means of a traffic simulation study, Van Arem et al. (2006) examined the traffic flow effects of Cooperative Adaptive Cruise Control. This ACC system exchanges information with the vehicle ahead, so that it can follow this vehicle more closely. The results indicated an improvement of traffic flow stability expressed by fewer shockwaves and smaller standard deviations of speed, and a slight increase of traffic efficiency indicated by higher queue discharge flows.

In summary, earlier research shows that in-vehicle technology has promising benefits for the transport system. However, also some concerns were expressed. For example, although these intelligent systems aim to support the driver, they might lead to unintended use of the systems (i.e. behavioural adaptation), distraction, loss of driving skills and information overload

(Dragutinovic et al., 2004). Besides these concerns, also inconsistent impacts were found. For example, the use of ACC systems could contribute to reducing head-tail accidents, but it could also reduce the traffic throughput, depending on the system settings (Minderhoud, 1999). Despite the increasing amount of knowledge of driver support systems, it can be concluded that there are no simple, straightforward assumptions on how these systems will influence driving behaviour and traffic flow performance. Many effects are still unknown and more research is required (Van der Heijden & Marchau, 2005).

In spite of their potential, the take-up of driver support systems in the market is very slow. For example, the development of ACC systems started more than 25 years ago, whereas nowadays only a small percentage of (luxury) cars are fitted with this system. The main reasons for this slow take-up are legal barriers, the competitive situation of the automotive sector, the high cost of the technology, the lack of consumer demand, the lack of information about the potential benefits and a clear business case. The European Commission recently launched the Intelligent Car Initiative to find solutions to the mobility problems and to improve the take-up of driver support systems (European Commission, 2006). The initiative has three objectives: (1) coordinate and support the work of relevant stakeholders, (2) support research and development and (3) create awareness among consumers and decision makers.

The development of in-vehicle technology is driven by several factors (Van Arem, 2007). On the one hand, public authorities and road operators recognize that driver support systems offer possibilities to alleviate the problems on their roads. On the other hand, car industries and suppliers consider the systems an important product innovation and a competitive advantage. And moreover, the capabilities of information and communication technology increase rapidly, resulting in a technology push of driver support systems. But the end users of such systems, that are the drivers, form the most important factor. Without their willingness to have and use driver support systems, these systems simply will not contribute to the solution of the transport problems. This is why the starting point of the research in this thesis is the driver's perspective. Based on his preferences for assistance with the driving task, an in-vehicle system – the Congestion Assistant – was developed, that was further assessed on its impacts on the driver and the traffic flow. Note that the term the driver refers to both male and female drivers, although the masculine form is used in the remainder of this thesis.

1.2 Research objectives and scope

1.2.1 Research objectives

Until now, the development of driver support systems has been strongly technology driven. However, the success of these systems is highly dependent on the willingness of drivers to have and use this in-vehicle technology. The first objective of this research is therefore to gain more knowledge of the driver's point of view towards intelligent vehicles. The corresponding research question to be answered is:

What are the needs of the driver with respect to driver assistance?

More than 1000 Dutch car drivers were asked to what extent they would like to have assistance from their cars with certain driving tasks and situations. There appeared to be a significant need for driver support in congested traffic situations. Based on these preferences, the so-called Congestion Assistant was developed. It is important to know if drivers are able and willing to interact with this in-vehicle system. Therefore, the second objective of this research is to assess the behavioural responses of the driver to the Congestion Assistant. The corresponding research question to be answered is:

What are the impacts of the Congestion Assistant on the driver, in terms of driving behaviour, mental workload and acceptance?

Individual driving behaviour determines to a large extent how efficient and safe the traffic flow behaves. It is important to know how changes in driving behaviour due to driving with the Congestion Assistant are related to the performance of a whole traffic flow. The third objective of this research is therefore to assess the influence of the Congestion Assistant on traffic flow characteristics. The corresponding research question to be answered is:

What are the impacts of the Congestion Assistant on the traffic flow, in terms of traffic efficiency and traffic safety?

It is expected that the car driver of tomorrow will have a variety of driver support systems at his disposal that assist him with the driving task and, in turn, will affect the transport system. The answers to the above research questions contribute to more insight into driver assistance in general and a Congestion Assistant in particular.

1.2.2 Scope

The scope of the research described in this thesis is limited as follows. First, it focuses on driver assistance that supports the driver with the operational and tactical levels of the driving task (see also Section 2.2.1). These levels include, for example, maintaining a proper speed and distance, lane-keeping and overtaking. Navigation systems that support the driver with the strategical level of the driving task are not taken into account. Furthermore, systems that aim at mitigating accidents, such as in-vehicle emergency call (eCall), and systems that are directly related to vehicle dynamics, such as Anti-lock Braking System (ABS) or Electronic Stability Control (ESC), are also not considered.

Second, the research focuses on driver assistance in passenger cars. This choice was motivated by the fact that passenger cars take an active part in traffic performance and traffic safety. For example, passenger cars account for more than 75% of all vehicle kilometres driven in the Netherlands (CBS, 2005). Moreover, passenger cars are often involved in accidents: about 65% of the road deaths and 70% of the in-patients were car drivers and passengers in the Netherlands in 2002 (SWOV, 2005).

Third, the scope of this research is on user acceptance assessment and impact assessment of driver support systems in general and the Congestion Assistant in particular. This research provides no detailed information about the technology used by driver support systems, such as sensors, cameras and wireless communication. It supposes reliable systems that work correctly without any false alarms. Also implementation issues, such as socio-economic and legal issues, are no part of this research.

Finally, this research concentrates on the functional aspects of driver support systems. Less attention is paid to aspects surrounding the user interface of such systems, although it is recognized that a proper design of the user interface is of importance to the system's acceptance and efficacy.

1.3 Research approach

Basically, three research methodologies were used to provide answers to the research questions: survey, driving simulator and traffic simulation. A user needs survey was conducted to assess the perceived needs of the driver for assistance with the driving task. The results of this survey served as a basis for creating the Congestion Assistant. The impacts of the Congestion Assistant on the driver were investigated by means of a driving simulator experiment. A microscopic traffic simulation study was performed to assess the impacts of the system on the traffic flow.

Figure 1.1 shows the outline of the remainder of this thesis. Chapter 2 presents more information about the field of driver support systems. It discusses several classifications of the systems and gives examples of systems that are under investigation or already available on the market.

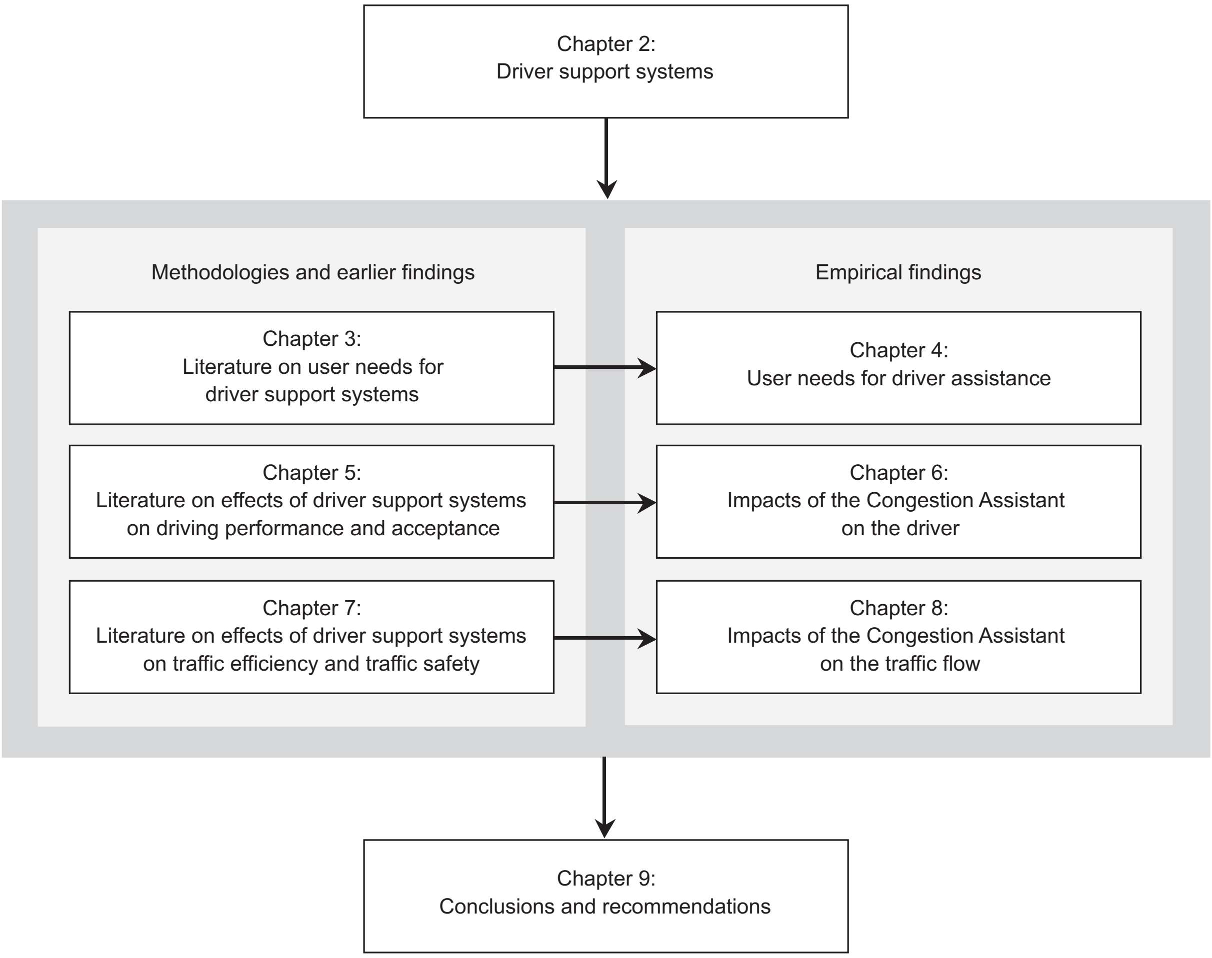


Figure 1.1: Outline of the remainder of this thesis

Chapter 3 presents common research methodologies for exploring user needs for driver support systems. In addition, it discusses the results of earlier research into these user needs. The findings of this chapter were used for the design of our user needs survey described in Chapter 4. This chapter also presents the results of the survey that was completed by more than 1000 Dutch car drivers. The findings were used to develop the Congestion Assistant, an in-vehicle system that supports the driver in congested traffic situations on a motorway.

Chapter 5 provides common research methodologies for exploring the impacts of in-vehicle technology on driving behaviour, mental workload and acceptance. It also discusses the results of earlier research into the impacts of systems similar to the Congestion Assistant on the driver. The findings of this chapter were used for the design of our driving simulator experiment described in Chapter 6. This chapter also presents the results of the experiment in which 37 participants gained experience with the Congestion Assistant. The findings were used in the subsequent traffic simulation study.

Chapter 7 describes common research methodologies for exploring the impacts of in-vehicle technology on traffic efficiency and traffic safety. It also presents the results of earlier research into the impacts of systems similar to the Congestion Assistant on the traffic flow. The findings of this chapter were used for the design of our traffic simulation study described in Chapter 8. This chapter also discusses the results of the study based on several variants of the Congestion Assistant with different equipment rates on a four-lane motorway with a lane drop.

Finally, Chapter 9 discusses the outcome of the total research project. It summarizes the results from the previous chapters by answering the three research questions. Next, some directions for further research are given. The chapter ends with general implications and conclusions.

1.4 Scientific and practical relevance

This research resulted in more insight into the user needs for driver assistance and the impacts of the so-called Congestion Assistant on the driver and the traffic flow. The main contributions can be summarized as follows.

1.4.1 Scientific relevance

The Congestion Assistant developed in this research is based on driver preferences instead of technological possibilities. These driver preferences were investigated by means of a user needs survey. In contrast to earlier research that generally concentrated on ‘ready to use’ driver support systems, the survey explores a broad range of possibilities for driver assistance. Our approach is therefore considered more worthwhile in gaining knowledge of when and how car drivers want to be assisted by their cars.

This knowledge is further extended by the driving simulator experiment that provides insight into the interaction of the driver with the Congestion Assistant and its functions. By selecting the participants of the driving simulator experiment from the respondents to the user needs survey, correlations between needs and acceptance were explored. The results from the experiment revealed to be consistent with the results from the survey. Hence the survey can be regarded as a valid method for the indication of user needs for congestion assistance.

The microscopic traffic simulation study contributes to more insight into the prospects of the Congestion Assistant regarding the efficiency and safety of a traffic flow. The simulation environment ITS Modeller was adapted to incorporate changes in individual driving behaviour due to the Congestion Assistant. This contributes to the development of a new generation of traffic flow models that include both drivers and new technologies, such as driver support systems. The reference situation in which no vehicles were equipped with the system was calibrated and validated using data measured on the Dutch A12 motorway. The

ITS Modeller was able to reproduce the onset of congestion due to a lane drop in agreement with the A12 data.

An extensive assessment of driver assistance with respect to user needs and impacts on the driver and the traffic flow, as described in this thesis, has not been conducted before. Including the three parts enabled to use the outcome of one part as starting point for the next. Besides, it enabled to study the agreement between the parts and showed that by using an integral approach additional information is obtained. For example, the positive effects of the Congestion Assistant found in the driving simulator experiment did not fully prevail in the traffic simulation study. Thus this research confirms the importance of investigating both changes in individual driving behaviour due to driver support systems, such as the Congestion Assistant, and the effects thereof due to interactions between equipped and non-equipped vehicles on the road.

1.4.2 Practical relevance

The outcome of this research is relevant to public authorities and road operators who can facilitate, stimulate or regulate driver support systems, depending on the contributions of these systems to solving the problems on their roads, such as accidents and congestion. The outcome is also interesting to car industries and suppliers who want to develop and sell driver support systems that contribute to the safety and the comfort of the driver.

The user needs survey revealed the perceived needs of the driver for support with several driving tasks and situations, and combinations thereof. The respondents particularly favoured warnings for downstream traffic conditions and warnings for traffic in blind spots. These results are starting points for car industries and suppliers that want to develop systems that meet the driver’s preferences. The respondents also indicated that the ideal support system should provide help with more than one driving task or situation. This emphasizes the importance of research into the functional operation of combined driver support functions, for example with respect to the user interface, sensor data fusion and vehicle-vehicle communication. Moreover, the user needs survey showed a great need for several forms of driver support in congestion. For that reason, the Congestion Assistant was developed consisting of a mix of informing, assisting and controlling functions.

The driving simulator experiment and the traffic simulation study revealed the impacts of the Congestion Assistant on the driver respectively the traffic flow. Participants of the driving simulator experiment particularly appreciated the Warning function of the system indicating a traffic jam ahead and the Stop & Go taking over the longitudinal driving task in the jam. They were not very enthusiastic about being slowed down by the Active pedal when approaching the jam at too high speed. The traffic simulation study showed that especially the Stop & Go reduced the amount of congestion significantly. These results on the Congestion Assistant point out several interests. For car industries and suppliers, it is relevant to know that people are willing to hand over the driving task in congestion to in-vehicle technology, such as the Stop & Go. For public authorities and road operators, it is important to realize that Stop & Go systems have promising impacts on the dissipation of traffic jams.

The implementation of in-vehicle systems is considered to be slow, despite the potential benefits of these systems. The Intelligent Car Initiative of the European Commission provides a further push towards smarter, safer and cleaner vehicles. This research contributes to the objectives of the Intelligent Car Initiative by creating awareness and acceptance of driver support systems and by examining and publishing the effects of such systems.

Chapter 2

Driver support systems

Driver support systems are in-vehicle applications that assist the driver in performing one or more elements of the driving task, such as maintaining a proper speed or avoiding an accident. This chapter outlines the systems that are meant by the term driver support systems. Classifications of the systems are presented as well as examples of the systems that are under investigation or already commercially available.

2.1 Introduction

A lot of research and development activities in the field of 'intelligent vehicles' take place worldwide, particularly in Europe, the United States and the Asia-Pacific region. An intelligent vehicle includes an information or control system that enhances the performance of the driver and/or the vehicle (Bishop, 2005). This information or control system can be called a driver support system. Besides the term driver support systems, a variety of other terms are found in literature, such as active safety systems, Advanced Driver Assistance Systems (ADAS), intelligent in-vehicle systems and Advanced Vehicle Control and Safety Systems (AVCSS). In this research the term driver support systems is used, because it refers to the most important characteristic of such systems: supporting the driver with the driving task. Related to driver support systems, also the more general term driver assistance and the more detailed term driver support functions are used in the remainder of this thesis.

Driver support systems sense the driving environment and provide information or vehicle control to assist the driver in optimal vehicle operation. The systems are developed through an evolutionary process towards fully automated driving, although this last step can rather be seen as a vision, since it is uncertain whether fully automated driving can be realized on normal roads (Ehmanns & Spannheimer, 2004). The market introduction of driver support systems finds itself in an early stage. The remainder of this chapter sheds more light on the area of driver support systems by classifying them and by presenting examples of systems that are under investigation or already commercially available.

2.2 Classification of driver support systems

The range of driver support systems is quite broad. Therefore, many classifications of these systems are possible. For the purpose of this research, the systems are classified according to:
- Level of support (informing, assisting or controlling)
- Communication (autonomous or cooperative)
- Functionality (longitudinal or lateral support)

Before describing these classifications, more information is given on the general driving task.

2.2.1 Driving task

The driving task is a comprehensive term that comprises all tasks that must be executed by the driver to reach his destination safely, comfortably and timely. A well-known hierarchical model of the driving task is that of Michon (1985). This model distinguishes three levels of the driving task: (1) strategic, (2) tactical and (3) operational. The strategic level involves general trip planning, including setting trip goals (e.g. minimize time, avoid traffic), selecting routes and evaluating the costs and risks associated with alternative trips. The tactical level involves negotiation of common driving situations, such as curves and intersections, gap acceptance, overtaking and obstacle avoidance. The operational level consists of the immediate vehicle control inputs, which are largely automatic action patterns (e.g. steering and braking). This hierarchy assumes a dynamic relation among concurrent activities at the three levels. Decision-making at these levels requires different types of information. While strategic decisions can be largely memory-driven, tactical and control decisions are based on the immediate driving environment and can thus be considered as mainly data-driven. Another difference between the levels concerns the time available for decision-making. General trip plans can be made in advance of a trip and more specific strategic decisions can be made while driving, often many minutes before execution. Tactical decisions are considered to take place in seconds, whereas operational decisions require only milliseconds to execute.

This thesis focuses on driver support systems that are related to the tactical and operational levels of the driving task and assist the driver with performing driving manoeuvres and controlling the vehicle. However, the hierarchical model of the driving task by Michon does not specify the control mechanisms that can be taken over by a driver support system. Minderhoud (1999) therefore proposed a control model of the driving task. This model includes the general steps of information processing by the driver: perception, interpretation, decision-making and action. A driver is assumed to constantly monitor his position and speed relative to the driving environment (e.g. other vehicles and road boundaries). His actions are adapted to this changing driving environment. The driving task can be described as a continuously repeated sequence of state perception, followed by predictions of the expected future state and a control decision after which the control action is carried out and a new state is formed (see Figure 2.1).

The steps in Figure 2.1 can be clarified as follows. The driver continuously perceives the actual traffic state by collecting information using his senses (e.g. sight, hearing, touch and smell). The state perception includes information about, among others, the own speed, the distance and relative speed to others, traffic signs and road geometry. Based on his state perception, the driver predicts the expected impact of possible control actions on the future state. For example, a driver following a slower vehicle can decide to overtake this vehicle and consider the consequences of this decision. The state prediction also incorporates information about expected movements of others and changes in the road configuration. Based on the future state prediction, control decisions are made and control actions are being initiated according to the driver's objectives and preferences. Examples of control actions are deceleration by applying the brake pedal or releasing the gas pedal, acceleration by applying the gas pedal and change of course by adjusting the steering wheel. The control actions affect the vehicle's state and consequently the traffic state, which results in a new state. This control model of the driving task is used in the next section to describe how a driver support system can influence the execution of the driving task.

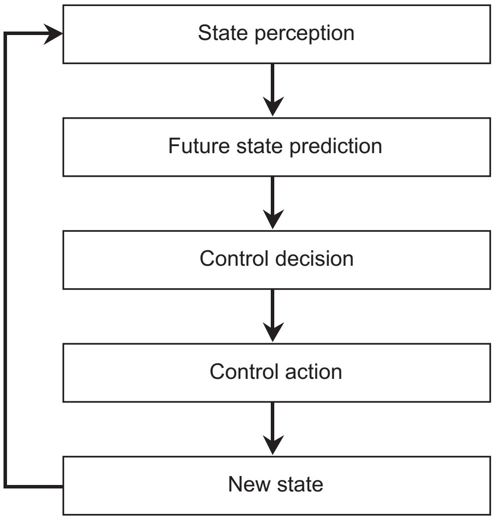


Figure 2.1: Control model of the driving task (based on Minderhoud, 1999)

2.2.2 Level of support

Driver support systems can take over elements of the driving task from the driver. Consequently, these systems can be classified according to the level of support they provide. A distinction can be made between informing, assisting and controlling systems, depending on the relation with the driving task (see Figure 2.2):

- An informing driver support system provides information about the supported task. For example, it can present the current speed limit on a display. The driver can use this information together with his own information about the traffic state and apply it in his control decision related to maintaining a proper speed.
- An assisting driver support system indicates a suggested action in potentially dangerous situations. For example, it can warn the driver by a sound signal if his vehicle unintentionally begins to move out of its lane. The driver can use this information when predicting the future state and apply it in his control decision related to lane-keeping.
- A controlling driver support system fully carries out the driving decisions and actions. For example, it can automatically adjust the vehicle's speed in order to maintain a proper distance to the vehicle in front.

Modalities for presenting information and warnings to the driver can be visual (e.g. text, icon), auditory (e.g. beep), haptic (e.g. counterforce of gas pedal) and tactile (e.g. seat vibration). Especially controlling systems change the role of the driver from operating a vehicle towards supervising a (partly) automated vehicle. In this research it is assumed that drivers can always overrule the driver support system, for example by neglecting the information or warnings given by the system or by taking over vehicle control from the system.

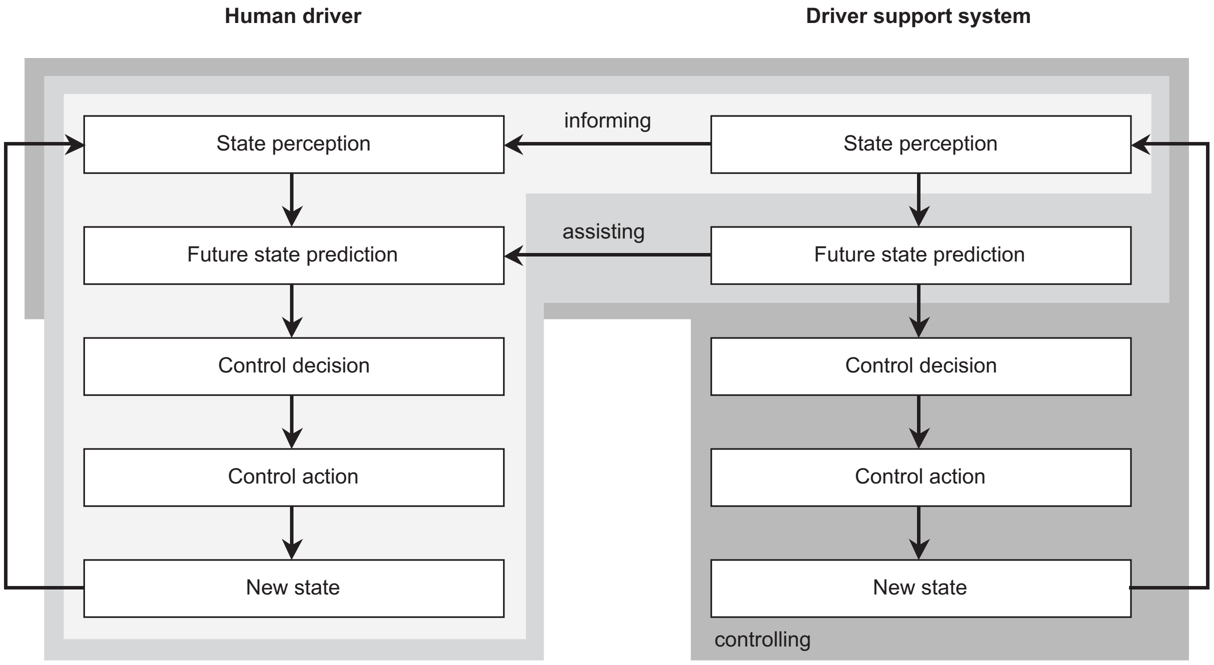


Figure 2.2: Driving task supported by informing, assisting or controlling driver support systems (based on Minderhoud, 1999)

2.2.3 Communication

Driver support systems can be autonomous or cooperative, depending on whether they can communicate with sources outside the vehicle. Autonomous systems rely upon onboard sensors to provide data for a particular application, whereas cooperative systems supplement onboard sensor data with information from other vehicles or the roadside (Bishop, 2005). Autonomous and cooperative systems are generally considered as first-generation and second-generation systems respectively. Autonomous systems focus on the vehicle as an isolated unit within the driving environment, while cooperative systems manage the vehicle's performance in the context of the overall road traffic system (European Commission, 2002).

Driver support systems use sensors for scanning the environment around the vehicle that enable early detection of potentially dangerous traffic situations (see Figure 2.3). For example, short-range and long-range radar sensors are used to detect obstacles in front of the vehicle, check the lane position and monitor the driver's blind spot.

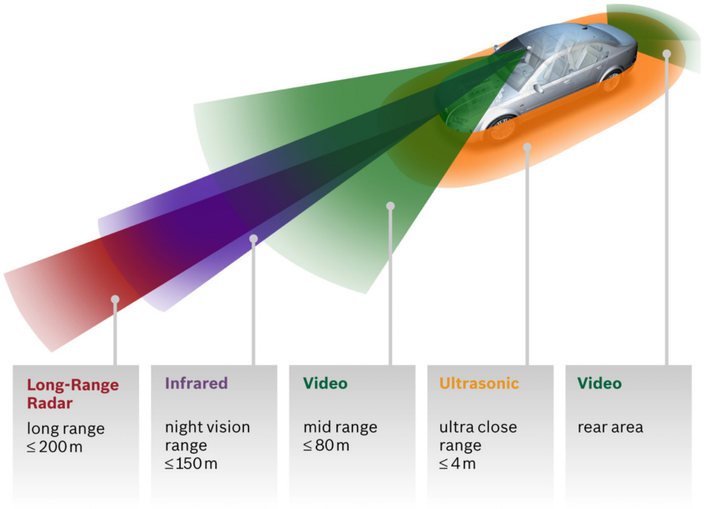


Figure 2.3: Sensor technologies for driver support systems (source: Bosch)

Cooperative driver support systems rely on wireless communication technologies, such as Dedicated Short Range Communications (DSRC), to enable data exchange with other vehicles or the infrastructure (Bishop, 2005). Both vehicle-vehicle communication and vehicle-infrastructure communication extend the 'information horizon' for the driver beyond the range provided by onboard sensors. This gives new opportunities to support the driver with his driving task. Examples of possible applications are:

- Traffic Light Assistant: the driver receives a warning to stop if the traffic light is in the stop phase and the system predicts that the driver will be in violation based on vehicle speed and braking status.
- Curve Speed Warning: the driver gets help with negotiating curves at appropriate speeds based on information communicated from roadside beacons
- Stop Sign Assistant: the driver is notified of the presence of stop signs or yield signs when it appears that he may drive through without stopping or slowing down to check traffic conditions.
- Foresighted Driving: the driver receives a warning whenever a safety-related critical situation occurs beyond the driver's field of view, such as a traffic jam ahead or reduced friction due to an icy road.

Onboard digital maps combined with satellite positioning can also be seen as a type of cooperative system, as positioning data is received from outside the vehicle (Bishop, 2005). Digital maps can replace roadside beacons, for example with respect to speed limit information or speed advice when approaching curves. Digital maps can also enhance the applications that use onboard sensor data, because they assist in the overall interpretation of the driving environment. For example, video data can be complemented by map data to improve lane detection and reduce false alarms.

2.2.4 Functionality

A well-known classification of driver support systems is related to the functionality of the systems. Generally, a distinction is made between systems that support the longitudinal driving task or the lateral driving task:

- Longitudinal driver support systems address traffic situations pertaining to the forward movement of the vehicle that are related to driving tasks, such as maintaining an adequate speed (e.g. in curves) and keeping a safe distance to vehicles or other traffic participants ahead.
- Lateral driver support systems address traffic situations pertaining to the sideward movement of the vehicle that are related to driving tasks, such as maintaining an adequate lateral position on the road, lane-change decisions and gap acceptance behaviour.

The next two sections describe examples of systems that are either available on the market or near market introduction (i.e. expected within 5 years). This review is not meant to be exhaustive, rather it discusses those systems that best represent the current field of driver support systems.

2.3 Longitudinal support

This section introduces examples of driver support systems that assist the driver with his longitudinal driving task.

2.3.1 Adaptive Cruise Control

Probably the most well-known driver support system is Adaptive Cruise Control (ACC). ACC allows a driver to set a desired speed as in normal cruise control. If a vehicle immediately ahead is moving at a slower speed, then throttle and brake are controlled to match the speed of the slower vehicle taking into account a time headway or gap selected by the driver (e.g. 1.0-2.2 s). The desired speed is automatically resumed when the lane ahead is unobstructed, resulting from either the slower vehicle leaving the lane or the driver changing to another (clear) lane. Figure 2.4 shows these operating modes of ACC. Most ACC systems operate only above a certain speed threshold (e.g. 30-40 km/h). Furthermore, the deceleration capability of the system is limited (e.g. -3 m/s^2). The driver is alerted to intervene if he is closing very rapidly on a vehicle in front and additional braking is needed to avoid a collision. Also the acceleration capability is limited (e.g. +1.5 m/s^2). Nissan was the first to introduce ACC in Japan in 1995. DaimlerChrysler followed in Europe and the United States in 1999 and 2001 respectively. ACC is now available from almost all automobile manufacturers. Generally, the systems are equipped into the upper-range vehicles, but ACC is beginning to come into the mid-range, for example on the Volkswagen Passat in Europe.

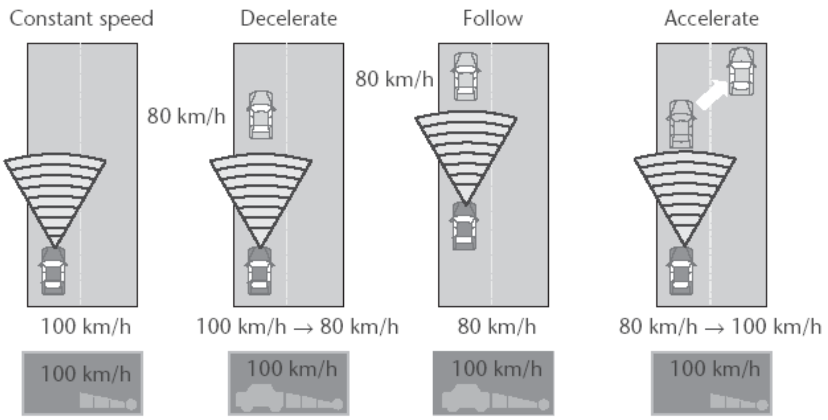


Figure 2.4: Operating modes of Adaptive Cruise Control (ACC) (source: Nissan)

2.3.2 Stop & Go

Stop & Go is an evolution of the ACC functionality, which operates in slow, congested traffic to follow the car immediately ahead. Stop & Go is also called low-speed ACC in contrast to high-speed ACC, which refers to the ‘normal’ ACC. Low-speed conditions are more complex than high-speed conditions and therefore require more system intelligence to assess the forward situation and judge that the car should move on or stop. Nissan and Toyota introduced Stop & Go into the Japanese market in 2004. Both systems operate quite differently. The Nissan system works from motorway speeds down to the low-speed following mode that disengages at 5 km/h. Below that speed threshold, the driver has to take over control and is responsible for stopping and starting the vehicle if necessary. The Toyota system works down to zero speed. It warns the driver when the vehicle in front is stopping and if there is no response the system will automatically bring the vehicle to a standstill. After that, the driver needs to initiate the resumption of forward motion. In fact, these Stop & Go versions perform a ‘stop and wait’ function, since the systems do not automatically start from a stop. Recently, Stop & Go is also introduced into the European market. Among others, BMW equips vehicles from the 5 series with the system (see Figure 2.5). The Stop & Go will brake to a standstill if required with a maximum deceleration capability of -4 m/s^2, then sets off again when the traffic ahead moves. If the standstill is longer than three seconds, a touch on the gas pedal is needed to set the vehicle off again.

Figure 2.5: Dashboard indicator showing Stop & Go enabled and tracking a vehicle ahead (source: BMW)

2.3.3 Forward Collision Warning and Avoidance

This section discusses three systems that supplement the driver's monitoring of the driving environment to detect imminent crash conditions in the longitudinal direction: Forward Collision Warning, Pre-crash Safety System and Forward Collision Avoidance.

Forward Collision Warning

Forward Collision Warning (FCW) detects impending crash situations and provides a warning to the driver using a variety of signals, such as sound signals, visual signals, seat vibration or slight seatbelt tensioning. Nissan was the first to offer Japanese car drivers FCW in 1988. The system developed by Eaton VORAD has been quite successful in the truck market in the United States since the early nineties and is currently available in the European truck market. FCW can also be sold as an after-market system. The system by MobilEye is developed for the after-market. It issues an audio-visual warning when the Time-To-Collision (i.e. the time required for two vehicles to collide if they continue at their present speed and on the same path) is smaller than a certain threshold (e.g. 3 s) alerting the driver to the danger and allowing appropriate action, such as braking or steering away from the obstacle ahead (Dagan et al., 2004). The MobilEye system also has a headway monitoring function. It displays the distance from the vehicle ahead (in seconds) and provides a visual indication of the safety level of this distance. A red safety level (i.e. unsafe) is shown when the time headway is 0.4 s or less for the 'normal' driving style setting (see Figure 2.6).

Figure 2.6: Display showing FCW developed by MobilEye

Although FCW has been introduced into the market, not a lot of passenger cars are equipped with the system. The biggest disadvantage of FCW is the minimal time available for a driver to respond to a warning for an imminent crash that is reliably detected. If the warning time were longer, this would increase the number of false alarms. This is why the car industry expects more from active braking systems, such as Pre-crash Safety System and Forward Collision Avoidance.

Pre-crash Safety System

The Pre-crash Safety System (PSS) can be seen as a step towards Forward Collision Avoidance. It includes a form of active braking, but without actually initiating it. Most systems use information from the ACC sensor to detect the risk of a collision with the vehicle in front. If the collision is unavoidable, the PSS precharges the brakes for increased braking force and retracts the seatbelts to help reduce injuries. So this system actually prepares the car for a collision to mitigate its impacts. Manufacturers explicitly inform the driver that the system should not be regarded as Forward Collision Avoidance. PSS is currently available in vehicles from manufacturers, such as Honda, Toyota and Nissan.

Forward Collision Avoidance

While PSS can be seen as a crash mitigation system, Forward Collision Avoidance (FCA) represents the ultimate crash avoidance system, in which sufficient braking is provided to really avoid the crash. It is expected that FCA will gradually progress from PSS by initiating the braking action earlier and increasing the deceleration capability. The complexity of avoiding a collision requires that FCA must possess a broad view and understanding of the total traffic situation. Although the car industry, mainly the Japanese, is doing intensive research into FCA, it is not known when the first systems will be available on the market.

2.3.4 Local Danger Warning

The former section presented driver support systems that supplement the driver's monitoring of the driving environment without communicating with other vehicles. In contrast to these autonomous systems, Local Danger Warning systems use vehicle-vehicle communication to extend the driver's horizon and warn the driver of dangerous situations ahead. This extra information gives the driver the opportunity to early adapt his speed and following distance and better anticipate the unforeseen situation. Examples of scenarios in which these systems can warn the driver are (Nöcker, 2004):

- Obstacles on the road due to accidents or traffic jams
- Reduced visibility or reduced friction due to bad weather

Local Danger Warning systems use wireless communication technologies, such as Wireless Local Area Network (WLAN). As soon as two vehicles are in communication range, they connect automatically, establish an ad hoc network and exchange data. The range of a single WLAN link is limited to a few hundred meters, but in case of no direct connectivity, multi-hop communication is used, so that data are forwarded from one vehicle to another to another, et cetera. Driver support systems using WLAN need a certain frequency band. It is expected that the 5.9 GHz frequency band will become available for these applications in Europe at the end of 2010 (source: Car 2 Car Communication Consortium).

2.3.5 Speed Alerting and Limiting

Speed alerting and limiting systems, in Europe also known as Intelligent Speed Adaptation (ISA), are aware of a predetermined maximum speed (e.g. the legal speed limit) and either provide feedback to the driver when he is driving faster or limit the vehicle's speed to comply with the set speed. Manual speed alerting systems are pre-set by the driver and generally provide audio and/or visual warnings. These systems are currently available in most new vehicles. However, road authorities regard particularly automatic speed alerting systems as a key system for improving traffic safety. Contrary to manual systems, these systems automatically determine the maximum speed, being the legal speed limit, and alert the driver when exceeding this speed limit. Warnings are generally audio, visual or haptic (e.g. counterforce of gas pedal). In early testing, the speed limit information was received from roadside transponders. Currently, this information is obtained from digital maps that need to be used with satellite positioning. Digital maps can also provide the driver with information about, for example, schools and sharp curves, so that he can adapt his speed when approaching these areas. In the Netherland, a pilot study is running with Intelligent Speed Information (in Dutch: Intelligente Snelheids Informatie) (source: iSi). Car drivers hear a child's voice from their navigation system that warns them for a nearby school.

Especially Europe is developing and testing systems to electronically assist the driver in maintaining a proper speed. Major work has been undertaken in Sweden, the United Kingdom, the Netherlands and France. Also the European Commission initiated projects on ISA, such as SpeedAlert (ERTICO, 2005) and PROSPER (Sundberg & Myhrberg, 2006). The availability of up-to-date speed limit information in digital maps is of major importance to the implementation of ISA. Currently, nation- or European-wide information is to a large extent lacking. However, the first commercial (small-scale) speed alert systems have emerged on the market, for example as extensions of existing route navigation systems. The SpeedAlert developed by Smart Car Technologies in Australia is also developed for the after-market (see Figure 2.7). The system alerts the driver when he is speeding, but it can also alert the driver to speed and red light cameras, and school zones. It currently covers the Sydney Metropolitan, but the working will be extended to other cities and even other countries.

Figure 2.7: SpeedAlert working on a PDA or mobile phone (source: Smart Car Technologies)

2.3.6 Vision Enhancement

Two systems that can enhance the driver's perception of the driving environment are Adaptive Front-lighting System and Night Vision.

Adaptive Front-lighting System

The Adaptive Front-lighting System (AFS) illuminates the areas in front and to the sides of the vehicle path to optimize the headlight beam in response to ambient weather and visibility conditions, vehicle speed and road curvature. Current systems calculate the necessary change in the position of the headlights based on parameters, such as speed, steering-angle and yaw rate. The beam is directed exactly where the vehicle is heading with patterns adjusted down and outward for low-speed driving, while light distribution is longer and narrower at high speeds to increase visibility at farther distances. More advanced systems will use digital maps and satellite positioning to have preview information about upcoming curves. The headlight beam is then aimed into the curve even before the vehicle reaches it, to present the driver an optimal view. Automobile manufacturers, such as Audi and Lexus, have released vehicles equipped with AFS since 2002. Nowadays, many offer these systems on their vehicles.

Night Vision
This system helps the driver with detecting objects on or near the road, such as pedestrians and animals, beyond the view of the vehicle's headlights. Generally, this information is gathered by an infrared camera and projected on a display in front of the driver (e.g. head-up display mounted on the windscreen). Cadillac was the first worldwide to bring Night Vision into the market in 2000. However, Cadillac does not offer this system anymore, because their far-infrared system resulted in poor image quality particularly on warm nights (IVsource, 2005). Currently, the trend in Night Vision is to use near-infrared systems instead of far-infrared. Among others, BMW equips vehicles with Night Vision based on this technology (see Figure 2.8). Honda introduced Night Vision that also incorporates a Pedestrian Detection Warning into the Japanese market in 2004.

Figure 2.8: Night Vision (source: BMW)

2.4 Lateral support

This section introduces examples of driver support systems that assist the driver with his lateral driving task.

2.4.1 Lane Departure Warning

Lane Departure Warning (LDW) warns the driver if the vehicle starts to leave the lane unintentionally (i.e. without using the indicator). Several warning signals are available, from beeps to simulated rumble strip sounds to seat vibrations. LDW must extract knowledge of the lane boundaries and the vehicle's position within the lane. This can be done via: (1) magnetic markers in the roadway, (2) digital maps and highly accurate satellite positioning and (3) image processing. Generally, the detection of existing lane markings is preferred using image processing. This is also why most systems operate at speeds above 50 km/h. LDW originally entered the heavy truck market in Europe in 2000, followed shortly thereafter by introductions in the United States. Next, the systems became available to car drivers in Japan. In 2005, Nissan and Citroën fitted the systems into their vehicles in the United States and Europe, respectively. The LDW by Citroën detects an unintentional lane-change at speeds of 80 km/h or above. A vibrating mechanism mounted in the car seat is triggered on the side corresponding to the direction of vehicle drift to alert distracted or drowsy drivers. LDW can also be an after-market system.

2.4.2 Lane Keeping Assistant

The Lane Keeping Assistant (LKA) reduces the driver's need to make the frequent minute steering corrections that are a normal part of driving, especially on motorways. The system detects the lane boundaries like LDW and uses steering actuation to add torque to the steering wheel. The driver must continue to provide steering inputs, otherwise the system will provide a sound signal and turn off. This is to ensure that drivers are not tempted to use it as a 'hands-off' system. LKA was initially introduced into the Japanese market by Nissan in 2001 and is now available from all major manufacturers there. In 2006, Lexus started offering LKA on their vehicles in Europe. The system operates in combination with ACC. When ACC is activated, LKA helps to maintain the vehicle's position in its lane by applying corrective steering responses. When ACC is not activated, the system works as LDW providing audio-visual warnings when drifting out of the lane.

2.4.3 Side Collision Warning and Avoidance

Two systems that can enhance the driver's perception of the driving environment to the sides of his vehicle are Blind Spot Monitoring and Lane Change Assistant.

Blind Spot Monitoring

This system assists the driver by detecting the presence of vehicles in the driver's blind spot. Blind Spot Monitoring can be applied in urban areas, for example when turning right at an intersection. However, most current systems particularly facilitate safe lane-changes on motorways. Generally, cameras are used that are incorporated into the vehicle's side mirrors. An audio or visual warning is provided when vehicles in adjacent lanes do not permit a safe lane-change manoeuvre. Among others, Volvo introduced Blind Spot Monitoring into the market in 2005. The system shows an orange warning light in the side mirror where the vehicle is present (see Figure 2.9). It is active at speeds above 10 km/h and reacts to vehicles that are driven at up to 20 km/h slower or 70 km/h faster than the vehicle to which it is fitted. The monitoring area is about 9.5 m long and 3 m wide.

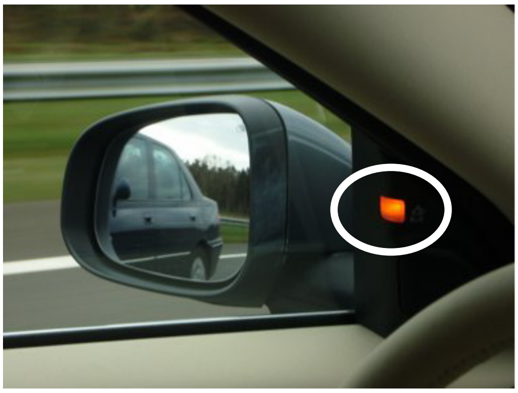


Figure 2.9: Blind Spot Monitoring by Volvo

Lane Change Assistant

The Lane Change Assistant (LCA) extends monitoring beyond the blind spot by also detecting vehicles in adjacent lanes that may be rapidly approaching and could pose a hazard in a lane-change manoeuvre. An example of available LCA systems on the market is the one offered by Volkswagen. This system monitors the rear and side areas of the vehicle via radar sensors in the rear bumper. It signals a potential collision risk via a warning light in the side mirror. The monitoring range is about 50 m to the rear and 3.6 m to the sides of the vehicle.

2.4.4 Driver Monitoring

Generally, this system is designed to detect that a driver is drowsy or not alert, to warn the driver of this diagnosis and in some cases to take over control of the vehicle if the driver does not respond to the warnings. Delphi is a leader in the development of systems for Driver Monitoring. A combination of the vehicle's behaviour (e.g. steering wheel movements, lane deviation) and the driver's physiological state (e.g. head movements, eyelid movements) provide data on driver drowsiness or alertness, as well as information about whether the driver's gaze is focused on the road. Although much research is concentrated on Driver Monitoring, the system is so far hardly available on the market. Recently, Lexus introduced the system into the European market. It works with a camera mounted on top of the steering column, which monitors the position of the driver's head when driving (see Figure 2.10). Should potential danger arise and the driver is not looking forward, an alarm will quickly be sounded and the brakes briefly applied. This version of Driver Monitoring shows close resemblance to FCW.

Figure 2.10: Driver Monitoring (source: Lexus)

2.5 Conclusions

This chapter presented the variety and functionality of driver support systems that are being developed or already commercially available. Most current systems are autonomous systems that do not communicate with other vehicles or the infrastructure. Recently, the development of driver support systems is more and more directed at cooperative systems that use vehicle-vehicle or vehicle-infrastructure communication.

Despite the research and development efforts, the market introduction of driver support systems finds itself in an early stage (Van Arem et al., 2004). Car manufacturers employ a rather conservative strategy, because they are uncertain about the financial risks and the usability of driver support systems. Governments and road operators are uncertain about the actual impacts of driver support systems on traffic safety and traffic efficiency, which makes them hesitant to take measures to facilitate, stimulate or regulate the introduction of these systems. This research aims at reducing the above uncertainties by gaining more knowledge of the user needs for driver support systems and the impacts of these systems on the driver and the traffic flow.

A key condition for the deployment of driver support systems is the existence of a market. Therefore, the willingness of drivers to have these systems is of major importance. Step one in this project was to investigate the user needs for driver assistance (see Chapter 4). But first, the next chapter will discuss the methodology of survey research and the findings of earlier studies into the user needs for driver support systems.

Chapter 3

Literature on user needs for driver support systems

The driver plays an important role in the development of driver support systems. After all, it is unproductive to invest effort in designing and building systems if they are never purchased and used. So it is necessary to know to what extent drivers would like to have 'intelligent vehicles'. This chapter describes the research methodologies for exploring user needs for driver support systems. In addition, it presents the results of earlier research into these user needs. The chapter concludes with implications for this research. The findings of this chapter were used for the design of the user needs survey discussed in Chapter 4.

3.1 Introduction

A successful introduction of driver support systems strongly depends on the willingness of drivers to buy and use the systems. Therefore, it is important to know to what extent drivers are eager to have such ‘intelligent vehicles’. Identification of user needs is essential for both system design and system assessment (Zhang et al., 1998). For system design it is important to know what system should be designed to best meet the user needs, while system assessment focuses on whether the developed system performs as intended and meets the user needs in practice. Therefore, the aim of user needs analysis is twofold (Robin-Prévallée et al., 1998):

- Identify the wishes, requirements, capacities and limitations of users, which are important to consider in designing driver support systems that meet users needs.
- Identify criteria – based on these wishes, requirements, capacities and limitations – against which the characteristics of the support system will be judged.

Several methodologies can be used to assess the user needs for driver support systems. Since drivers can be regarded as ‘hands-on’ experts in car driving, it is relevant to ask them about their perceived needs for assistance with the driving task. This research methodology is further described in the next section. After that, the results of earlier research into user needs for driver support systems are discussed. The chapter concludes with implications for this research.

3.2 User needs surveys

3.2.1 Marketing research

User needs for driver assistance can be studied in a number of ways. One way is to let experts define the user needs. This was for example the case in the study of Fastenmeier et al. (1992) and in most technology driven studies, such as the GIDS project (Michon et al., 1993). Another way is to let end users indicate their needs. Consequently, principles of marketing research can be used. Marketing research is about consumer behaviour: activities people undertake when obtaining, consuming and disposing of products and services. One of the oldest marketing formulas is AIDA, which stands for Attention, Interest, Desire and Action (Strong, 1925). The model assumes that the consumer should first be made aware of a specific product or service. Through the years, the AIDA model has been adapted and extended. The basics, however, can still be found in more recent marketing models, such as the Consumer Decision Process (CDP) model (Blackwell, et al., 2001). The first step of the CDP model – need recognition – plays an important role in research into user needs for driver support systems. Because most of these systems are not yet available on the market, we are dealing with latent needs. This can be illustrated by the results of the Continental survey conducted in Germany (Boekhoff, 2006). It was found that only about one third of the respondents has heard of or read about driver support systems.

To reveal latent needs, consumers have to be reminded of these (potential) needs. A frequently used method for this is questioning people. Questioning methods can be divided into qualitative and quantitative techniques. Examples of qualitative techniques include in-depth interviews and focus groups (i.e. group discussions). These techniques are generally used for exploratory purposes and have a small-scale character. Quantitative techniques, such as questionnaires, are large-scale and aim at presenting a phenomenon in numerical values.

Both techniques might complement another. For example, Comte et al. (2000) first conducted focus groups to capture the issues to be evaluated in the subsequent questionnaire. Conversely, the results from the questionnaire could be interpreted by the in-dept comments obtained in the focus groups.

3.2.2 Stated preference data

Stated preference data are often gathered to reveal latent needs for products that are not yet available on the market. These data provide insight into people's choices in hypothetical situations. In general, two approaches can be distinguished: (1) compositional and (2) decompositional (Timmermans et al., 1994). A compositional approach involves that respondents indicate their preferences for several product features or attributes directly. Consider for example a distance keeping support system that helps the driver with maintaining a safe following distance to the preceding vehicle. Respondents could be asked to evaluate different levels of support (e.g. warning, assisting, controlling) and different levels of price (e.g. €500, €1500, €2500). The overall preference is composed by the explicitly measured preferences for separate attributes. In a decompositional approach – also known as conjoint analysis – respondents have to indicate their overall preference for a hypothetical alternative described in terms of attributes (e.g. level of support and price) and attribute levels (e.g. warning and €500 versus assisting and €1500). In this way, respondents are forced to make trade-offs among attributes. The overall preference is decomposed into the weights these respondents attach to the separate attributes.

3.3 User needs for driver support systems

A variety of studies examined the opinions of potential users about hypothetical forms of driver support systems. In this case, the word 'opinion' stands for a broad concept, including attitudes, perceptions, preferences, needs and acceptability. The studies mainly discussed one or more specific systems, rather than driver assistance in general. The most frequently used methods for investigating these opinions were focus groups and questionnaires. Most questionnaires were set-up according to the compositional approach of stated preference research. This section gives an overview of the needs for driver support systems among potential users who were not (yet) exposed to the systems.

3.3.1 Conceptual framework of user needs

The explored studies are discussed using a conceptual framework that was developed in this research project (see Figure 3.1). This framework shows an overall picture of earlier research into user needs for driver support systems. The user needs for a system may be influenced by characteristics of the driver and the system. Besides, they may be influenced by characteristics of the traffic scene. The different influences on the user needs for driver support systems, indicated by the arrows in the conceptual framework, are explained below by elaborating on the explored studies.

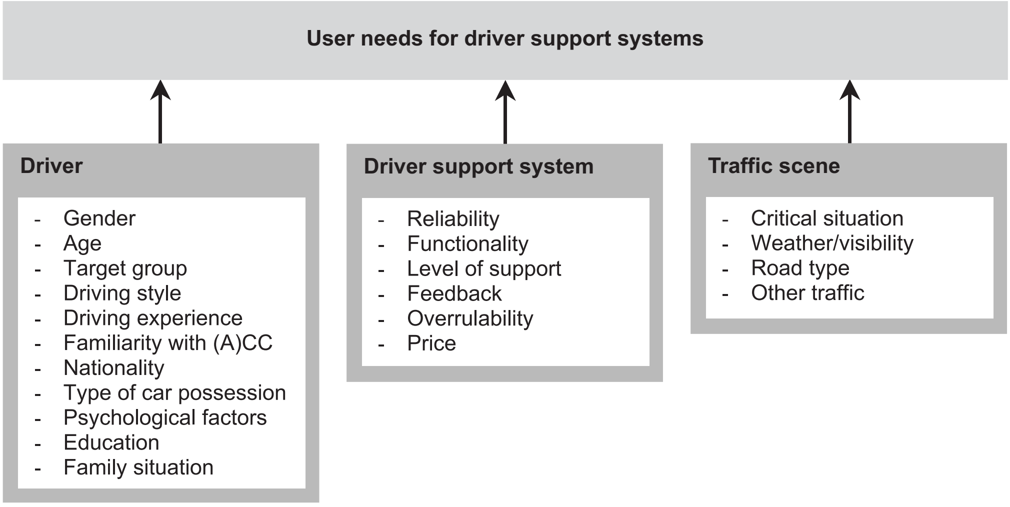


Figure 3.1: Conceptual framework of user needs for driver support systems

3.3.2 Characteristics of the driver

The opinion about driver support systems appears to be influenced by characteristics of the driver. *Gender* seems to have an effect on the needs for driver support systems. Generally, women were more positive about help from their cars during driving than men (TRG, 1998; Chalmers, 2001). However, Blythe & Curtis (2004) found that men had a more positive attitude than women thinking driver support systems should assist or take over instead of simply warn. Also the preferences for systems can differ between men and women. According to Piao et al. (2004) men liked Adaptive Cruise Control (ACC) best and women Intelligent Speed Adaptation (ISA). Also Rienstra & Rietveld (1996), Garvill et al. (2003) and Molin & Brookhuis (2007) found that women were more in favour of speed-regulating devices. Possibly, men are less willing to accept such devices, since speeding is more related to typical male (macho) behaviour. However, in the COMUNICAR survey no differences with respect to gender were found (Mariani et al., 2000). With respect to *age*, older drivers were generally more positive about driver assistance than younger drivers (CRA, 1998; TRG, 1998; Chalmers, 2001; Garvill et al., 2003; Piao et al. 2004; Molin & Brookhuis, 2007). Elderly people may be less confident in their driving skills, which can lead to a greater need for in-vehicle systems to help them maintain safe driving. However, Hipp et al. (2006) found that truck drivers older than 50 years were less positive about driver assistance than truck drivers aged 20-35 years. Furthermore, it seems to matter to which *target group* drivers belong. Truck drivers considered driver support systems to be more attractive than car and van drivers (Marchau, 2000). Also Chalmers (2001) found that bus and truck drivers generally expressed a greater need for driver support systems than private drivers. This might be due to the fact that bus and truck drivers generally do not have to pay themselves for a system in contrast to car drivers. Concerning *driving style*, cautious and careful drivers were more positive about help from their cars than drivers with a more ‘sportive’ driving style (TRG, 1998; Chalmers, 2001).

Next to driving style, *driving experience* seems to be of influence on the needs for driver support systems. Drivers with a lower annual mileage thought that such systems were more attractive compared to driver with a higher annual mileage (Marchau et al., 2001). Garvill et al. (2003) and Molin & Brookhuis (2007) found a similar result with respect to the acceptability of ISA. Frequent drivers might consider themselves more capable of performing driving tasks without assistance than less frequent drivers. Besides the amount of kilometres driven, personal experience with certain situations may affect the opinion about driver support systems. Particularly drivers that had encountered a (near-) accident due to tiredness appreciated a driver monitoring system (Bekiaris et al., 1997; CRA, 1998). Personal experience with congestion also motivated positive reactions to a Stop & Go (TRG, 2003). With respect to *familiarity with (A)CC*, Piao et al. (2004) stated that the indicated needs for ACC were connected with the dissemination activities about ACC for the last ten years. They also found that drivers with experience with cruise control were significantly more willing to purchase an ACC than those without. However, Marchau (2000) found no influence of familiarity with driver support systems such as ACC and the indicated preferences for driver assistance. There seems to be a relation between *nationality* and driver support systems as well (Mariani et al., 2000). For example, Swedish drivers indicated a greater need for automatically set cruising speed than Italian drivers, whereas this was the opposite for warnings on car overtaking. Marchau et al. (2001) found large differences between opinions of drivers in six European countries. On average, Greek drivers considered driver support systems to be attractive, while Finnish drivers thought that these systems were unattractive. Compared to English drivers, Dutch and Norwegian drivers were less positive about ISA (TRG, 2003). These contrasts might be attributed to differences between countries regarding the concern about safety and efficiency in relation to other issues, such as perceptions of risks and opinions about car driving.

Type of car possession seems to be another explanatory variable. In the COMUNICAR survey it was found that owners of a city car had different opinions about driver support systems than owners of an upper class car (Mariani et al., 2000). Marchau (2000) found that business drivers perceived such systems as being more attractive than private drivers did. *Psychological factors* seem to influence in particular speed-regulating devices. People who frequently violate speed limits were more against speed limiters according to Rienstra & Rietveld (1996). Also Garvill et al. (2003) found this relationship: the stronger the moral obligation to keep speed limits, the more positively were different ISA devices evaluated. In a few studies, the effects of *education* and *family situation* on the perceived needs for driver support systems were studied. Highly educated people were more against speed limiters according to Rienstra & Rietveld (1996). However, Marchau (2000) as well as Molin & Brookhuis (2007) found no differences between preferences of drivers based on their level of education. TRG (1998) found that respondents with children younger than 15 years were more interested in ACC and Collision Warning than respondents with older children or without children.

In summary, a variety of driver characteristics seem to influence the perceived needs for driver support systems, although there is not always consensus on the exact relations. However, in particular gender, age and driving experience appear to be most discriminating. Especially women, older drivers and drivers with a high annual mileage show interest in getting support from their cars when driving.

3.3.3 Characteristics of the system

The opinion about driver support systems is affected by characteristics of the system as well. The general accepted notion in literature with respect to *reliability* was that systems should be 100% reliable and have no false alarm rates. Besides, the *functionality* of the system appears to be of influence. This refers to the driving tasks or situations that the system supports. In general, lane-keeping systems did not seem to be very popular among drivers. Lane Departure Warning (LDW) was rated (much) lower than Stop & Go, ACC and ISA (Piao et al., 2004). The results of the IN-ARTE survey also showed that drivers were indifferent to lateral control functions (Wevers et al., 1999). Reasons for this might be that LDW is generally not suitable for all road types (e.g. depending on lane markings) and that this system provides little direct safety or comfort benefits compared to the other systems. However, participants in the study of Regan et al. (2002) felt that LDW was a good idea, particularly when driving for long periods of time. In contrary to lane-keeping systems, anti-collision systems seemed to be popular. CRA (1998) found that all participants viewed Collision Avoidance Systems favourably. The IN-ARTE survey revealed a strong preference for warnings on front obstacles and warnings to slow down (Wevers et al., 1999). The results of the COMUNICAR survey showed that driver support functions related to enhancing safety were valued as the most preferred ones (Mariani et al., 2000). These included for example: automatically set cruising speed, and warnings on front obstacles and car overtaking. Also systems that provide visual support were rated high. According to Blythe & Curtis (2004), respondents were most positive about Collision Warning and Prevention, ACC and Driver Alertness Monitoring. Chalmers (2001) indicated that generally there was a major acceptability of systems that control longitudinal distances between vehicles. Molin & Marchau (2004) studied how drivers perceived ACC, ISA and navigation in terms of personal driving goals and how these goals in turn affected overall preferences for the systems. They found that especially changes in safety and comfort levels influenced these preferences.

Besides type of system, *level of support* seems to affect the needs for driver assistance. CRA (1998) found that the appeal to ACC was more limited, possibly due to the automatic control of car-following. Similarly, the results of the IN-ARTE survey showed that drivers were generally negative about automatic intervention, probably because personal control is a crucial issue in driving behaviour (Wevers et al., 1999). Also the COMUNICAR survey revealed a greater need for information and warnings than automatic actions (Mariani et al., 2000). Blythe & Curtis (2004) found that nearly half of the drivers thought driver support systems should simply warn the driver, while the other half thought these systems should assist (38%) or take over (16%). Truck drivers questioned by Hipp et al. (2006) preferred warnings because they were sceptical about active control, afraid of technical failures and concerned about loosing vehicle control. Regan et al. (2002) concluded that drivers generally are not in favour of systems that take away driver control, especially if they perceive that these systems might compromise safety. Perhaps this was also the reason for respondents to the SASPENCE survey to prefer an informing mode on urban roads, an assisting mode on rural roads and a controlling mode on motorways (Fiorani et al., 2005).

Closely linked with level of support is type of *feedback*. Modalities for giving feedback to the driver can be visual (e.g. text, icon), auditory (e.g. beep, voice), haptic (e.g. counterforce of gas pedal) and tactile (e.g. vibration in steering wheel). The COMUNICAR survey revealed that warning signals should be given visually or with a sound, rather than with a synthesised voice (Mariani et al., 2000). Garvill et al. (2003) concluded that light and sound signals when exceeding the speed limit were preferable to a display presenting the current speed limit and a counterforce of the gas pedal making it more difficult to exceed the speed limit. These results were observed too by TRG (2003). However, they also found that drivers were more positive about haptic ISA after having gained experience with it in a driving simulator. Frequently, the type of feedback is considered in such (follow-up) studies, rather than in user needs surveys. *Overrulability* appears to be important in the acceptance of driver assistance as well. It is about the possibility for the driver to overrule (i.e. ignore) the system, for example by turning it off. Regan et al. (2002) came to the conclusion that voluntary driver support systems, which drivers can choose to disable, were more acceptable among drivers than mandatory systems, which cannot be turned off by the driver. If the driver cannot switch off the system, the attitude of the majority of respondents was negative (Blythe & Curtis, 2004). Only one application, Collision Warning and Prevention, still received a favourable attitude. According to Comte et al. (2000), participants thought mandatory ISA would be most useful, however, they preferred the idea of a voluntary system.

Opinions about driver support systems are also influenced by the *price* of these systems. Van der Heijden & Molin (1999) found that respondents were prepared to pay little for ISA. However, the willingness to purchase such a system seemed to be higher when it was combined with other systems. Marchau et al. (2001) concluded that, as expected, higher prices had a negative influence on the acceptability of driver assistance. A majority of respondents were either not prepared to pay anything extra for driver support systems (50%) or would be willing to pay a sum of up to £500 (€755) (37%) (Blythe & Curtis, 2004). Regan et al. (2002) concluded that the costs to purchase and maintain a system is a critical factor influencing the driver's willingness to buy and use a technology. Like type of feedback, price is also frequently considered in (follow-up) studies that include gaining experience with a system, rather than in user needs surveys. TRG (1998) referred in her study to earlier research showing that 30% of the participants were willing to purchase an ACC at an average price of $490 (€377), rising to 87% and $616 (€474) after prototype rides.

In summary, characteristics of driver support systems affect the perceived needs for them. Besides reliability, particularly functionality, level of support and overrulability appear to be important. There is not always consensus on the exact relations between needs and functionality, but it is clear that most drivers appreciate a system giving information or warnings that they can overrule. Preferences for the type of feedback and the price are generally obtained from studies with a driving simulator or instrumented vehicle, after the drivers have gained experience with the system in question.

3.3.4 Characteristics of the traffic scene

The opinion of the driver about driver support systems may also be influenced by characteristics of the traffic scene. In general, there seems to be a greater need for driver assistance in *critical situations*, such as near-accidents. Bridger & Patience (1998) concluded that in normal driving situations, the driver wants to be in control. In more adverse situations, assistance from the car is wanted and in dangerous situations, the driver even relies on assistance from the car. A higher level of support in more critical situations was also found by Wevers et al. (1999) in the IN-ARTE survey and by Fiorani et al. (2005) in the SASPENCE survey. According to Várhelyi (2000), a majority of respondents accepted ISA that warns the driver or even automatically reduces the driving speed in imminent crash situations. Concerning *weather/visibility*, TRG (1998) showed that drivers would like to use ACC especially when it is foggy or at night. Most respondents were positive about ISA during slipperiness or reduced visibility situations (Várhelyi, 2000). The COMUNICAR survey revealed that respondents were interested in visual support in poor visibility situations (Mariani et al., 2000). Respondents to the SASPENCE survey particularly preferred driver assistance with regulating speed and car-following during adverse weather conditions and on slippery roads (Fiorani et al., 2005).

Furthermore, *road type* seems to influence the needs for driver assistance. Schmeidler (2002) reported that respondents thought ACC was especially useful on motorways and rural roads, while ISA should be used mainly on urban roads. This result on ISA was also found by Van der Heijden & Molin (1999) and Van Hoorebeeck (2000). Participants in the study of Regan et al. (2002) felt that LDW was a good idea in rural areas. Fiorani et al. (2005) stated that drivers perceived assistance with keeping a proper speed and distance to be especially useful when driving on motorways. The presence of *other traffic* may also affect the opinions about driver support systems. TRG (1998) found that drivers liked to use ACC or Collision Warning when the traffic density was low. However, the IN-ARTE survey revealed the opposite: the acceptance of autonomous braking (e.g. by ACC) was higher in situations with dense traffic (e.g. convoy driving) as compared to clear running situations (Wevers et al., 1999). This result was also found in the SASPENCE survey, where driver assistance was perceived useful in dense traffic with accidents or queues ahead (Fiorani et al., 2005).

In summary, the opinion of the driver about driver support systems especially seems to be influenced by adverse driving conditions. Drivers expressed a need for assistance in potentially dangerous situations (e.g. imminent crash, reduced visibility). Moreover, some systems are appreciated more on certain road types than others. For example, drivers tend to prefer ACC on motorways, LDW on rural roads and ISA on urban roads.

3.4 Implications for this research

One of the aims of this research project is to study the needs for driver assistance. Great importance is attached to the driver's point of view, since it would be unproductive to invest effort in developing driver support systems that will never be purchased and used. Therefore, a user needs survey was conducted in which car drivers could indicate their perceived needs for 'intelligent vehicles'.

The results of earlier research discussed in this chapter revealed a variety of user needs for hypothetical forms of driver support systems. These needs seem to be influenced by characteristics of the driver, the system and the traffic scene, as presented in the conceptual framework (see Figure 3.1). Despite the many interrelations, the following characteristics are assumed to be essential for research into user needs for driver assistance. First of all, drivers differed in their opinions based on the functionality of the system. Thus, it seems to matter which driving tasks or situations a system aims to support. It also appears to be important how the system supports the driver, thus with what level of support (e.g. informing, assisting, controlling). Concerning the traffic scene, it is notable that the needs for driver support systems seem to depend on how critical the driving situation is and on what road type the driver is driving. Of the driver characteristics mentioned in this chapter, particularly the driver's gender and age revealed a relation with the needs for driver assistance. These characteristics were also taken into account in our user needs survey to provide a more consistent view on the relations involved.

Following from the literature review, it was found that the previous studies generally concentrated on perceived needs for 'ready to use' driver support systems, such as ACC and ISA. In contrast to this approach, we decided to focus on possibly not (yet) existing forms of driver assistance. Consequently, our user needs survey was aimed at discovering the needs for support with several driving tasks and situations, and desired combinations thereof. It was expected that in this way a better understanding could be gained into when and how car drivers want to be assisted by their cars during car driving. Therefore, the user needs survey presents hypothetical driver support functions instead of systems. So rather than showing a system like ISA, several driver support functions that regulate speed are shown. This means that a broad range of possibilities for driver assistance was explored. Although the decompositional approach seems to be better suited for investigating trade-offs between user needs, the compositional approach was applied in the survey because this approach has the advantage of taking into account a large amount of features (e.g. driver support functions). The next chapter will discuss the set-up of the user needs survey and its results on the driver's needs for driving assistance.

Chapter 4

User needs for driver assistance

A user needs survey was conducted to investigate the perceived needs for driver assistance with certain driving tasks (e.g. lane-keeping, congestion driving) and situations (e.g. driver fatigue, reduced visibility). This chapter describes the set-up of the survey and discusses the results. More than 1000 Dutch car drivers completed the Internet questionnaire. The results of the survey showed that warnings for downstream traffic conditions (e.g. congestion) were favoured. Moreover, the respondents indicated that their ideal support system should assist with critical situations, such as an imminent crash or reduced visibility. The findings of this chapter were used to design the so-called Congestion Assistant. The impacts of this system on the driver and the traffic flow are discussed in Chapters 6 and 8 respectively.

4.1 Introduction

The user needs for driver assistance were assessed by means of a user needs survey. The main research questions to be answered by the survey were as follows:

- What are the needs of the driver with respect to driver support functions?
  - To what extent do drivers want assistance from their cars during driving?
  - Which driving tasks and situations should be supported?
  - On which road type and with what level of support?
- What are the needs of the driver with respect to the ideal driver support system?
  - What is the ideal assistance according to the driver?
  - Which combinations of driving tasks and situations should be supported?
- What is the influence of driver characteristics on these needs?

The set-up of the user needs survey is described in the next section. After that, the results on the needs for driver support functions and the ideal driver support system are presented. These results are then discussed in the light of the research questions stated above. Furthermore, the methodology used is considered. After discussing the results and the methodology, this chapter ends with conclusions.

4.2 Set-up of user needs survey

4.2.1 Questionnaire design

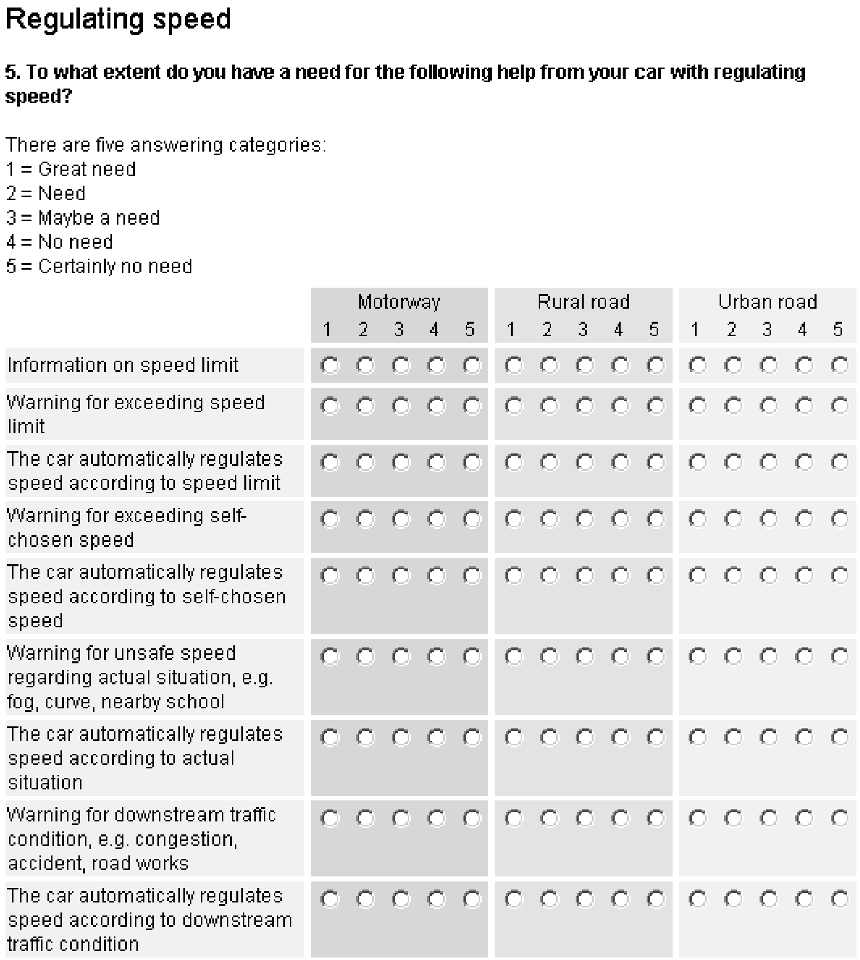
Driver support functions

The questionnaire starts with information about the goal and procedure of the survey. Next, some background questions on car possession and usage are asked, followed by information about ways in which the car can assist the driver with his driving task. The next part of the survey contains questions on the needs for driver support functions. Table 4.1 shows the driving tasks and situations that are included in the questionnaire. The driving tasks relate to the operational and tactical level of driving (Michon, 1985). A distinction was made between three road types: motorways (M), rural roads (R) and urban roads (U).

Table 4.1: Driving tasks and situations in the survey

Driving tasks
Regulating speed (M, R, U)
Lane-keeping (M, R, U)
Car-following (M, R, U)
Lane-changing (M, R, U)
Congestion driving (M, R, U)
Negotiating non-signalised intersections (R, U)
Negotiating signalised intersections (R, U)
Situations
Reduced visibility
Driver fatigue
Imminent crash

For each driving task and situation, several driver support functions are defined. Participants had to indicate on a five-point scale to what extent they felt a need for these functions on each road type (1=great need, 5=certainly no need). Figure 4.1 shows an example of speed assistance. The driver support functions are informing, assisting or controlling. In this survey, it was assumed that the driver could overrule the driver assistance, for example by turning it off.



Regulating speed

5. To what extent do you have a need for the following help from your car with regulating speed?

There are five answering categories:
1 = Great need
2 = Need
3 = Maybe a need
4 = No need
5 = Certainly no need

	Motorway					Rural road					Urban road				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Information on speed limit	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Warning for exceeding speed limit	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
The car automatically regulates speed according to speed limit	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Warning for exceeding self-chosen speed	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
The car automatically regulates speed according to self-chosen speed	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Warning for unsafe speed regarding actual situation, e.g. fog, curve, nearby school	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
The car automatically regulates speed according to actual situation	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Warning for downstream traffic condition, e.g. congestion, accident, road works	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
The car automatically regulates speed according to downstream traffic condition	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Figure 4.1: Example of a survey question: speed assistance

Ideal driver support system

After having introduced possibilities for driver assistance, the next part of the survey focuses on the ideal driver support system. A ‘personalized’ table is presented first that shows all driver support functions for which the participant has a significant need according to his or her previous answers (i.e. answer category 1 or 2). It was assumed that drivers would prefer a system consisting of less support than a summing-up of single functions, since this summing-up might be ‘too much’. Participants could formulate their ideal driver support system by indicating at most six favoured driving tasks and situations that the system should provide assistance with. These tasks and situations correspond to the ones in the preceding part of the survey (see Table 4.1). When participants were indifferent or negative about the driver support functions, they did not have to fill in the questions on the ideal system. The questionnaire ends with background questions about socio-economic variables and a possibility to add comments.

Internet questionnaire

Participants were asked to fill in the user needs survey on the Internet. This medium was selected for the following advantages: (a) personalization of the questionnaire by interactively showing relevant questions and responses based on previous answers, (b) collection and storage of data in an electronic database and (c) quick and cheap way of data gathering. The user needs survey was online from 24 August until 1 October 2004. Appendix A contains the questionnaire as shown on the Internet (in Dutch). Before putting online, the questionnaire was improved (i.e. shortened and clarified) based on a pilot study with twenty-one people. General guidelines for designing and implementing Internet surveys were followed to increase the user-friendliness (Schonlau et al., 2002). Examples of these guidelines include an introduction to the survey, the order of the questions, the number of questions per screen, an indication of survey progress and the provision of incentives.

4.2.2 Invitation of participants

A market agency, RM Interactive, was called in to invite members of her Internet panel. These members were paid for their participation. Besides, they could win a gift voucher. A contract was signed that guaranteed 300 completed questionnaires. It was tried to represent the target group of Dutch car drivers (i.e. people with a driving licence) with respect to gender, age and education. Participants were also invited via personal and business contacts. They could win a gift voucher as well. An invitation by e-mail containing a hyperlink to the questionnaire was sent to family, friends, colleagues and representatives of the government and the business sector. It was also asked to forward the e-mail to possibly interested others (snowball method). Furthermore, an invitation to the questionnaire was put on the websites of research organisation TNO and consumer organisation ANWB.

4.2.3 Data collection and analysis

The questionnaire was completed by 1152 respondents. 103 respondents did this in less than 10 minutes. These answers were left out of consideration, because it was assumed that one could not seriously fill in the survey in less than 10 minutes. The results were therefore based on the answers from 1049 respondents. The dependent variables were the perceived needs for the driver support functions measured on a five-point rating scale (1=great need, 5=certainly no need) and the driving tasks and situations to be supported by the ideal system measured on a dichotomous scale (0=no, 1=yes).

Frequency statistics were used to gain more insight into the needs for driver assistance. In addition, McNemar tests were performed to distinguish between significantly greater needs for one thing compared to another. The McNemar test is a non-parametric test for comparing two related dichotomous variables (Rice, 1994). It focuses on changes in responses using the chi-square distribution (see Appendix B). The test was applied to study differences in needs between the driver support functions with the greatest expressed needs and between the most chosen driving tasks and situations to be supported by the ideal system. Besides, it was used to investigate whether the needs for driver assistance differed per road type and level of support. The answers with respect to the driver support functions were split into '(great) need' (i.e. categories 1 and 2) and 'other' (i.e. categories 3 to 5). Because not all possible comparisons were examined, a conservative p-level was used, namely $p<0.001$. Chi-square tests were used to investigate whether the distributions of variables (e.g. gender) differed between groups (e.g. sample versus target group). These tests were also used to study the influence of driver characteristics on the results from the user needs survey. The analyses concentrated on the sub-sample of respondents that indicated a need for the type of driver assistance in question. It was assumed that driver characteristics were of influence on these needs, when the distributions of the variables (e.g. age, average annual mileage) in the sub-sample were different from the distributions of these variables in the total sample. When $p<0.05$, the results were considered to be statistically significant.

4.3 Results

4.3.1 Respondents

Of the 1049 respondents, 757 were male and 292 were female. The average age of the respondents was 41 years (standard deviation 12, minimum 18, maximum 79). Most of them were highly educated. Table 4.2 shows some characteristics of the sample and the target group of Dutch car drivers owning a driving licence (CBS, 2003). The distributions of gender, age and education in the sample significantly differed from those in the target group. Nevertheless, it was assumed that the results of the sample gave a clear indication of those of the target group. Unweighted data were used for all analyses (see also Section 4.3.4).

Table 4.2: Characteristics of sample (n=1049) and target group of Dutch car drivers

Characteristic	**Sample**	**Dutch car drivers**
Gender		
Male	72.2%	54%
Female	27.8%	46%
Age		
18-24 years	6.8%	8%
25-44 years	51.9%	44%
45-64 years	38.7%	36%
>64 years	2.6%	12%
unknown	0.1%	-
Education		
primary education	0.2%	4%
lower secondary education	9.2%	24%
higher secondary education	22.6%	44%
higher education/university	67.8%	28%
other	0.2%	-

Table 4.3 shows more background information about the sample. It can be seen that most respondents had a driving licence for more than 10 years, possessed their own car and drove in it frequently. Almost half of the respondents were somewhat familiar with Adaptive Cruise Control (ACC). Nearly all respondents indicated to use the Internet regularly.

Table 4.3: Background information about the sample (n=1049)

Characteristic	Sample
Frequency of car driving	
>3 times a week	71.8%
1-3 times a week	18.8%
1-3 time a month	6.3%
<1 time a month	3.1%
Years of driving experience	
< 5 years	8.9%
5-10 years	17.5%
>10 years	73.6%
Average annual mileage	
<10.000 km	23.9%
10.000-20.000 km	38.9%
>20.000 km	37.2%
Type of car possession	
no car	6.6%
private	79.2%
business	13.2%
other	1.0%
Familiarity with ACC	
not familiar with	25.4%
somewhat familiar with	50.0%
(very) familiar with	24.6%
Frequency of Internet usage	
rarely	-
sometimes	2.7%
regularly	97.3%

4.3.2 Driver support functions

More insight was gained into the needs for certain driver support functions by analysing the answers to the first part of the questionnaire. In this part the respondents indicated to what extent they want assistance from the car: support with which driving tasks and in which situations, on which road type and with what level of support.

Driving tasks and situations

The driver support functions for which the greatest needs were expressed were related to the following driving tasks and situations: regulating speed, lane-changing, negotiating intersections, imminent crash and reduced visibility. Table 4.4 shows these functions based on the answers ‘great need’ and ‘need’ (i.e. categories 1 and 2, see Figure 4.1). Especially warnings for downstream traffic conditions and warnings for traffic in blind spots were favoured.

Table 4.4: Ten driver support functions with the greatest expressed needs (n=1049)

Driver support function	**(Great) need**
1. Warning for downstream traffic conditions – motorway	90.2%
2. Warning for downstream traffic conditions – rural road	84.3%
3. Blind spot warning during lane-changing – motorway	82.1%
4. Blind spot warning at non-signalised intersection – urban road	82.0%
5. Blind spot warning at non-signalised intersection – rural road	79.4%
6. Blind spot warning during lane-changing – rural road	75.0%
7. Blind spot warning at signalised intersection – urban road	73.3%
8. Blind spot warning at signalised intersection – rural road	71.4%
9. Warning for imminent crash	70.2%
10. Presentation of badly visible objects on windscreen	70.0%

It was investigated to what extent respondents indicated a significantly greater need for certain driver support functions than others. From pairwise comparisons using the McNemar test, it appeared that the perceived needs for the first function ‘warning for downstream traffic conditions – motorway’ significantly differed from the other functions. This also applied to the functions 2 to 5, which significantly differed from the first function and from the functions 6 to 10. Based on this, the ten driver support functions with the greatest expressed needs could be divided into three groups, see Table 4.4. Within the groups the perceived (great) need for the specific functions did not differ significantly, except for function 2 versus 5.

Furthermore, the results showed that only three respondents were indifferent or negative (i.e. categories 3 to 5) about all driver support functions presented in the first part of the survey. 107 respondents out of 1049 (10.2%) indicated to have (certainly) no need for lane-keeping support. Also support with lane-changing was not very wanted. Almost 9% of the respondents did not need any help from the car with this driving task. However, it should be kept in mind that more than 82% of the respondents indicated to have a (great) need for a blind spot warning during lane-changing on motorways.

Road type

In general, there was a great need for driver assistance during driving on motorways. Respondents wanted less help from their cars with driving on rural roads and even less on urban roads. However, this tendency did not hold up for all driver support functions. It appeared that information about speed limits and warnings for exceeding the speed limit were most wanted on rural roads. Some functions were wanted on rural roads as much as on motorways, among which warnings for an unsafe speed regarding the actual situation (e.g. fog, curve) and automatic lane-keeping on winding roads. Other functions scored higher on rural roads than on urban roads, among which warnings for opposing traffic during lane-changing and information about approaching a dangerous (non-)signalised intersection. There was no greater need for specific functions on urban roads compared to rural roads.

Level of support

Respondents would mainly like their cars to help them by giving information or warnings. They indicated hardly any need for controlling driver support. The most unpopular driver support functions were related to automatic actions with respect to lane-changing, negotiating intersections and lane-keeping. However, in some cases respondents did want the car to take over control. Respondents preferred automatic actions from the car when they want to maintain a self-chosen speed on motorways or rural roads. They also would like the car to take over the longitudinal driving task or even the whole driving task when they are driving in traffic jams, irrespective of the road type.

4.3.3 Ideal driver support system

More insight was gained into the ideal driver support system by analysing the answers to the second part of the questionnaire. In this part the respondents indicated at most six driving tasks and situations that the ideal system should provide help with. Three respondents were indifferent or negative about all driver support functions presented in the first part of the survey. Therefore, they did not have to fill in the second part about the ideal driver support system. Answers from the remaining 1046 respondents were used for the analyses below.

Driving tasks and situations

The respondents chose various driving tasks and situations to be supported by their ideal driver support system. Most respondents (56.2%) thought the ideal system should assist with six driving tasks and situations. According to 29 respondents (2.8%), the ideal system should only help with one driving task or situation. Table 4.5 shows the driving tasks and situations that were chosen the most for being supported by the ideal system. Especially support with reduced visibility and imminent crash situations were favoured. Next, several driving tasks on motorways, and subsequently, rural roads were mentioned. Only the last driving task of the ten most chosen tasks and situations was related to urban roads. The ideal system should not support lane-keeping on urban roads and negotiating signalised intersections on rural and urban roads. Less than 2.8% of the respondents indicated to want assistance from the ideal system with these driving tasks.

Table 4.5: Ten most chosen driving tasks and situations to be supported by the ideal system (n=1046)

Assistance with	Yes in system
1. Reduced visibility	60.5%
2. Imminent crash	56.2%
3. Car-following – motorway	51.1%
4. Regulating speed – motorway	43.8%
5. Congestion driving – motorway	42.3%
6. Driver fatigue	35.3%
7. Regulating speed – rural road	33.8%
8. Car-following – rural road	28.5%
9. Negotiating non-signalised intersection – rural road	22.4%
10. Negotiating non-signalised intersection – urban road	19.9%

It was investigated to what extent respondents indicated a significantly greater need for certain types of assistance in the ideal system than others. It appeared that the perceived needs for the first three types of assistance did not significantly differ from each other. However, the difference between these three and the rest was significant. So help from the ideal system with reduced visibility, imminent crash and car-following on motorways was most wanted of all. Within the group of type 4 to 10 the perceived needs for the specific types of assistance differed significantly, except for consecutive numbers. The three most frequently mentioned pairs of driver assistance consisted of combinations of the three most chosen ‘single’ driving tasks and situations in the ideal system.

Ideal system in relation to single functions

Respondents had to formulate their ideal driver support system by indicating driving tasks and situations – thus, no functions – that the system should support. Therefore, the ideal system was not ‘directly’ linked to the single driver support functions. Although there was not a direct relationship, it was studied to what extent the composition of the ideal system was related to the indicated needs for the driver support functions. Driving tasks and situations ‘corresponding’ with the driver support functions for which respondents indicated a (great) need, could or could not be chosen in the ideal system. For example, 64.9% of the respondents that indicated a (great) need for the presentation of badly visible objects on the windscreen wanted the ideal system to help with reduced visibility situations. In this case, most respondents that had a need for the single driver support function related to reduced visibility also indicated a need for help from the ideal system with this situation. So this result showed a certain consistency in the answers to the first and second part of the survey. However, this did not apply to, for example, help with negotiating signalised intersections on rural roads. Only 2.3% of the respondents that indicated a (great) need for blind spot warnings at signalised intersections on rural roads wanted the ideal system to help them with this driving task. It was concluded that when having to establish priorities, it seems that respondents thought it was more important to receive other types of assistance from the ideal system, for example support during reduced visibility situations, than support with negotiating signalised intersections.

4.3.4 Influence of sample characteristics

It was investigated whether the survey results were dependent on characteristics of the sample. First, the effects of corrected proportions between the sample and the target group were studied by weighting cases. Second, the influence of driver characteristics, such as age and driving experience, on the needs for driver assistance was examined. Finally, it was tested whether the way participants were gathered for the survey was of influence.

Weighting cases

The sample of the user needs survey significantly differed from the target group of Dutch car drivers with respect to gender, age and education. Therefore, the results are only valid for this subset of the target group. However, by weighting cases the proportions between the sample and the target group were corrected. Again, the needs for driver support functions and the composition of the ideal driver support system were analysed. With weighting cases, it appeared that the ten driver support functions with the greatest expressed needs and the ten most chosen driving tasks and situations to be supported by the ideal system were (almost) identical to those without weighting cases. It was concluded that, although the sample did not statistically resemble the target group, the results of the sample gave a clear indication of those of the target group.

Driver characteristics

The possible influence of eight driver characteristics on the survey results was examined, see Table 4.6. First, it was studied to what extent driver characteristics affected the needs for the ten driver support functions with the greatest expressed needs (Table 4.4). It appeared that most driver characteristics were not of influence on the indicated needs for the driver support functions. Only the type of car possession influenced the perceived needs for the presentation of badly visible objects on the windscreen. Owners of a business car indicated a greater need for this driver support function than owners of a private car.

Table 4.6: Driver characteristics and categories

Characteristic	Categories
Gender	male, female
Age	18-24 years, 25-44 years, 45-64 years, >64 years
Education	primary & lower secondary, higher secondary, higher & university
Frequency of car driving	>3 times a week, 1-3 times a week, 1-3 times a month, <1 time a month
Driving experience	<5 years, 5-10 years, >10 years
Average annual mileage	<10.000 km, 10.000-20.000 km, >20.000 km
Type of car possession	private, business
Familiarity with ACC	not familiar with, somewhat familiar with, (very) familiar with

Second, it was studied to what extent driver characteristics affected the needs for the most chosen driving tasks and situations to be supported by the ideal driver support system (Table 4.5). It can be seen from Table 4.7 that especially needs for help with congestion driving on motorways was influenced by several driver characteristics. However, driver characteristics were not of influence on the needs for help with imminent crash situations, car-following on motorways and driver fatigue situations. So respondents had a similar need for these types of assistance from the ideal driver support system, regardless of their background.

Table 4.7: Influence of driver characteristics on types of assistance in ideal driver support system

Assistance with	Driver characteristics of influence
Reduced visibility	gender
Imminent crash	-
Car-following – motorway	-
Regulating speed – motorway	gender
Congestion driving – motorway	gender, age, education, average annual mileage, familiarity with ACC
Driver fatigue	-
Regulating speed – rural road	gender
Car-following – rural road	age, familiarity with ACC
Negotiating non-signalised intersection – rural road	gender
Negotiating non-signalised intersection – urban road	gender

Table 4.7 can be clarified as follows. Gender appeared to have the biggest influence on the types of assistance wanted in the ideal driver support system. Men thought the ideal system should mainly support with congestion driving on motorways and with regulating speed on motorways and rural roads. However, women thought the ideal system should mainly support with reduced visibility situations and negotiating non-signalised intersections on rural and urban roads. The results indicated differences between certain age groups, but no ‘trend’ between young versus old could be found. Especially respondents aged 25-44 years appeared to have a great need for help with congestion driving on motorways. However, this group expressed a smaller need for help with car-following on rural roads compared to the other age groups. The results revealed that the higher one’s education, the more one indicated a need for support with congestion driving on motorways. Also respondents that drive more than 20.000 km a year had a great need for this type of support. The results further suggested that the more one was familiar with ACC, the more one had a need for this type of assistance in the ideal system as well. However, familiarity with ACC did not show a clear relationship with the need for help with car-following on rural roads. Respondents that were not familiar or very familiar with ACC indicated to have a stronger preference for this kind of support in the ideal system than respondents that were somewhat familiar with ACC. The frequency of car

driving, years of driving experience and type of car possession did not appear to have an influence on the composition of the ideal system.

Response group
Participants for the survey were invited via the market agency or via the personal and business contacts. It was studied whether this had consequences for the survey results. First, the two response groups were compared to each other with respect to the eight driver characteristics (e.g. gender, age). The groups significantly differed from each other with respect to all of the characteristics, except for average annual mileage and type of car possession. For example, the Internet panel consisted of (1) more female respondents, (2) more older respondents, (3) less highly educated respondents, (4) more respondents that drove over three times a week, (5) more respondents with over 10 years of driving experience and (6) less respondents that were (very) familiar with ACC.

Second, the two response groups were compared to each other with respect to their perceived needs for driver assistance (Tables 4.4 and 4.5). It appeared that the respondents had a similar need for the driver support functions, regardless of the way they were gathered for the survey. However, the two groups had different needs for support from the ideal system with congestion driving on motorways. Respondents from the self-gathered group indicated a greater need for this type of assistance than respondents from the Internet panel. This can possibly be attributed to the different composition of the two groups with respect to gender, age, education and familiarity with ACC. These variables already appeared to have an influence on the perceived needs for the ideal driver support system to provide help with congestion driving on motorways.

4.4 Discussion

4.4.1 Overview of results

Car drivers were asked to indicate their needs for assistance from their cars during certain driving tasks and situations by means of a user needs survey. This section discusses the perceived needs for driver support functions and the ideal driver support system. It subsequently presents on which road type and with what level of support the respondents would like to be assisted and the influence of driver characteristics on the needs for driver assistance.

The results showed that the respondents particularly favoured warnings for downstream traffic conditions and warnings for traffic in blind spots. Apparently, drivers appreciate being well informed when driving. Knowledge of what is happening further down the road (e.g. an accident or road works) can help the driver to accordingly regulate his speed or allows the driver to turn off the road and seek an alternative route to his destination. Being aware of what is happening in the direct vicinity of the car (e.g. another vehicle in the left blind spot or a bicycle in the right blind spot at an intersection) provides the driver with a more accurate idea of the situation, so that dangerous situations can be prevented or at least anticipated. Furthermore, the ideal driver support system seems to be personal, since the respondents chose various driving tasks and situations to be supported by the system. The majority of respondents, however, preferred the ideal system to give support with reduced visibility and imminent crash situations. Thus, drivers would like their cars to assist them in critical situations, which confirms the results of earlier studies (Bridger & Patience, 1998; Fiorani et al., 2005). Respondents indicated hardly any need for the driver support functions concerning lane-keeping. This type of assistance was unpopular in the ideal system as well. These findings are in accordance with earlier findings (Wevers et al., 1999; Piao et al., 2004).

Respondents particularly would like to have driver assistance on motorways. They want less help from their cars with driving on rural roads and even less on urban roads. This is probably due to the complexity of the traffic process, being more complex in urban environments compared to motorways. Perhaps drivers think that driver support systems are not fully capable of detecting and interpreting complex traffic situations well. Or they might be concerned about not being able to handle complex traffic situations together with the assistance provided by their cars. Some driver support functions, however, were more favoured on rural roads than on motorways and urban roads. These involved information about speed limits and warnings for exceeding the speed limit, which presumably have to do with the sometimes unclear speed limits on the Dutch rural roads. With respect to level of support, respondents would mainly like their cars to help them by giving information or warnings. Automatic actions from the car were unpopular. Many respondents indicated that they had a desire to stay in full command of the car. This corresponds to findings from literature (Hoedemaeker, 1999; Blythe & Curtis, 2004). However, in some cases respondents did want the car to take over control: when they want to maintain a self-chosen speed on motorways or rural roads and when they are driving in traffic jams, irrespective of the road type.

Driver characteristics did not influence the perceived needs for support with imminent crash situations. Evidently, this kind of support is important to all drivers regardless of their backgrounds. Gender revealed to affect the needs for driver assistance the most. Although men and women indicated equal needs, these needs differed per driving task or situation. For example, women indicated a greater need for help from the ideal system with reduced visibility situations, while men had a greater need for help with regulating speeds on rural roads. These findings are not consistent with earlier research, which pointed out that women were more positive about driver support systems, in particular speed-regulating devices (Rienstra & Rietveld, 1996; Molin & Brookhuis, 2007). Especially needs for assistance with congestion driving on motorways was influenced by several driver characteristics. In particular respondents that were male, aged between 25-44 years, highly educated or driving more than 20.000 km a year expressed a need for this type of support. Probably, these respondents frequently encounter traffic jams. Personal experience with congestion might cause positive attitudes to support with congestion driving, as was also found by TRG (2003).

4.4.2 Implications for driver assistance

It was noticed that the respondents have a need for a reasonable number of driver support functions. Furthermore, the respondents indicated that the ideal system should provide help with more than one driving task or situation. To fit these needs for driver assistance, it is assumed that ‘stand-alone’ driver support systems are not satisfactory. Therefore, a shift has to be made from systems that only include one kind of support to systems that consist of integrated driver assistance. Technical integration should be taken into account, so that different functions can use the same components, such as sensors. Aspects surrounding the Human-Machine-Interface (HMI) are important to prevent the driver from overload and confusion. Different functions should use one interface with information management to give priority to certain information. Attention should be given to the functional operation of integrated driver assistance as well. Systems should make use of each other’s information.

Consider, for example, warnings for imminent crash situations based on sensor data fusion or warnings for downstream traffic conditions based on vehicle-vehicle communication.

4.4.3 Conducting the survey

This user needs survey revealed the perceived needs for support with several driving tasks and situations, and desired combinations thereof. Compared to previous studies that generally focused on ‘ready to use’ systems, our study did not suggest a particular driver support system. Therefore, our approach was considered more worthwhile in gaining a better understanding of when and how car drivers want to be assisted by their cars during car driving. In the first part of the survey, the respondents had to express their needs for driver support functions, while in the second part they had to formulate their ideal driver support system by choosing a limited number of driving tasks and situations to be supported by this system. Because respondents had to establish priorities, this second part provided valuable, extra information about user needs for driver assistance.

The survey was distributed via the Internet. Despite the many benefits, selection bias can be regarded as a drawback of Internet questionnaires. Namely only people who (regularly) use the Internet can be researched. However, it should be kept in mind that the number of current Internet users in the Netherlands is high and still growing (CBS, 2004). In 2004, 72% of the Dutch people had ever used the Internet and 80% of the people aged 18-54 years indicated to have used the Internet the past four weeks. Nevertheless, it was recognized that the opinions of elderly drivers were to a large extent missing in this user needs survey. Furthermore, it should be asked how respondents (i.e. users of the Internet) were likely to differ from non-respondents. The fact that the respondents were more acquainted with new technology might have affected their views on driver assistance. For example, Chalmers (2001) found that those who use new technology as part of their lifestyle did not accept control of the vehicle being taken away from them. Apparently, this group is more concerned about the reliability of a system in terms of technical failure. Also the invitation of participants via personal and business contacts can lead to inherent bias. These people may be more willing to participate in the survey than others, for example, because they like the subject of the survey. Statistical tests revealed that response group (i.e. self-gathered or Internet panel) appeared to have an influence on the perceived needs for certain types of assistance in the ideal driver support system. This influence is likely due to the different composition of the two groups with respect to background characteristics, such as gender and age. The total sample did not significantly resemble the target group of Dutch car drivers with respect to gender, age and education. However, weighting cases tried to compensate for this bias. It was concluded that the results of the sample could be considered strongly directional for those of the target group.

The survey clarified to which extent drivers have a need for driver assistance. These needs might be influenced by the familiarity of respondents with forms of driver assistance. For example, familiarity with ACC affected the perceived needs for help with car-following on rural roads and congestion driving on motorways. This possibly also explains the great perceived need for support on motorways, because systems already available on the market, such as regular cruise control and ACC, are merely designed to operate on motorways. However, most of the systems do not exist (yet), so it is to some extent uncertain whether the respondents interpreted the hypothetical driver support functions correctly. Therefore, it was considered interesting to investigate whether the opinions ‘on paper’ would change after the respondents gained experience with the driver assistance. To verify this, respondents to the user needs survey were asked to participate in the driving simulator experiment (see Chapter 6).

4.4.4 Towards a Congestion Assistant

The survey results were used to design an in-vehicle system that would fit the needs of potential users. It appeared that more than 90% of the respondents indicated a need for warnings for downstream traffic conditions (e.g. congestion, road works). Almost 60% of the respondents would like the car to automatically drive in congestion. Moreover, the ideal driver support system should support the driver with congestion driving on motorways according to more than 42% of the respondents. Apparently, car drivers appreciate several forms of congestion assistance. It was therefore decided to design a so-called Congestion Assistant. Based on the survey results, this system should at least provide congestion warnings and automatic congestion driving. The first function can be regarded informing, while the second is controlling. The Congestion Assistant was complemented with an assisting function, namely haptic feedback. Although this function did not directly result from the user needs survey, it was assumed that it would fill up the ‘gap’ between the informing and controlling functions. It would give a counterforce of the gas pedal when the driver would approach a traffic jam at too high speed. Accordingly, the Congestion Assistant consists of a mix of informing, assisting and controlling functions to support the driver during congested traffic situations on motorways. The impacts of this system on the driver and the traffic flow were studied in the remainder of this research project.

4.5 Conclusions

This chapter presented the results from a user needs survey among 1049 Dutch car drivers. The respondents were asked to indicate their needs for support from their cars during certain driving tasks and situations. It appeared that warnings for downstream traffic conditions and warnings for traffic in blind spots were favoured. Apparently, drivers appreciate being well informed when driving a car. Furthermore, the respondents preferred the ideal system to give support in critical situations, such as an imminent crash or reduced visibility. These needs have implications for the design of driver support systems. One can expect that the integration of functions is sensible, for example by means of vehicle-vehicle communication that applies to functions such as warnings for downstream traffic conditions.

The results from the user needs survey served as input for the design of the so-called Congestion Assistant. This system consists of a mix of informing, assisting and controlling functions to support the driver during congested traffic situations on motorways. The next step in this project was to investigate the impacts of the Congestion Assistant on the driver by means of a driving simulator experiment (see Chapter 6). Changes in driving behaviour, mental workload and acceptance were topics of interest. But first, the next chapter will discuss the methodology of driving simulator experiments and the findings of earlier studies into the effects of driver support systems on driving performance and acceptance.

Chapter 5

Literature on effects of driver support systems on driving performance and acceptance

Changes in driving behaviour due to driver support systems determine how useful and effective these systems are. So it is necessary to know to what extent drivers are able and willing to interact with the systems. This chapter describes the research methodologies for exploring the impacts of in-vehicle technology on the driver. In addition, it presents the results of earlier research into the impacts of driver support systems related to congested traffic situations on driving behaviour, mental workload and acceptance. The chapter concludes with implications for this research. The findings of this chapter were used for the design of the driving simulator experiment with the Congestion Assistant discussed in Chapter 6.

5.1 Introduction

The deployment of driver support systems strongly depends on how drivers are able and willing to interact with these systems. It is therefore important to study the impacts of a system on the driver at an early stage in the development process. Behavioural responses of drivers to in-vehicle technology might be related to:

- Driving behaviour: What are the improvements in driving performance resulting from the support provided by the system? What are the unintended and unwanted changes in driving performance (i.e. behavioural adaptation) when driving with the system?
- Mental workload: What are the effects of the system on the total mental workload? Can the system be safely used in combination with the current driving task?
- Acceptance: What is the driver's attitude towards the system? To what extent does the system fit the driver's expectations of the perceived benefits of the system? What is the willingness to pay for the system?

Several methodologies can be used to assess the safety and utility of new in-vehicle technology. Ideally, the assessment of a system is based on measurements under a full-scale, real-life application. This is however not always practical, possible or safe. Therefore, driving simulators are often used to study the interaction between the driver and the system. This research methodology is further described in the next section. After that, indicators for measuring driving behaviour, mental workload and acceptance are presented. As we are interested in the impacts of the Congestion Assistant on the driver, the results of earlier research into these impacts of similar systems are subsequently discussed. The chapter concludes with implications for this research.

5.2 Driving simulator experiments

5.2.1 Using a driving simulator

A driving simulator has a wide range of research applications in the area of human factors. One application is the design and evaluation of driver support systems. A driving simulator enables to study the impacts of a system at an early stage in the development process on the driver in terms of driving behaviour, mental workload and acceptance.

Driving simulators present several advantages over other research methods such as field tests (Nilsson, 1993). The controlled and repeatable environment of driving simulators allows researchers to isolate experimental variables from other factors that might influence driver performance. So all participants in an experiment can be exposed to the same conditions. This makes driving simulators well suited for comparative effect studies where one or more factors are systematically varied, while all other factors are kept constant. In addition, driving simulators enable researchers to study driving behaviour under potentially dangerous situations that could not be replicated by field tests without exposing the participants or other road users to unacceptable risks.

Despite the advantages, using a driving simulator raises the question of validity: to what extent are results obtained in the simulator applicable to real-world driving? The capabilities of driving simulators can vary greatly, ranging from simple desktop-mounted systems to advanced installations capable of replicating driving motions and detailed virtual driving environments. However, no driving simulator can produce an entirely convincing illusion of real driving (Hakamies-Blomqvist et al., 2001). Therefore, it is reasonable to assume that a driving simulator will not result in the finest details of driving behaviour. Kaptein et al. (1996) pointed out that any use of driving simulators should be preceded by questioning whether the driving simulator is sufficiently valid for the application to be investigated. Validation studies involve the comparison of driving behaviour in a driving simulator with real-world driving behaviour, for example measured in an instrumented vehicle. A driving simulator is said to have absolute validity if the absolute effect size is comparable to the absolute effect size in reality. It has relative validity if the direction or relative effect size is the same as in reality. Hakamies-Blomqvist et al. (2001) stated that the relative validity of the VTI driving simulator can be considered good: changes in the driving situation systematically produced similar behavioural changes in real traffic and in the driving simulator. For example, the participants altered their lateral position and speed in the simulator in the same direction and by the same order as in real traffic. Also Godley et al. (2002) found that the participants reacted similarly in both the instrumented vehicle and the MUARC driving simulator, establishing relative validity. However, the participants drove faster in the instrumented vehicle, resulting in absolute validity not being established. From a review of validation studies, Kaptein et al. (1996) concluded that driving simulators generally show relative validity, for example with respect to speed and lateral control behaviour. They found evidence suggesting that the presence of a moving base and a higher image resolution might increase the validity of a driving simulator.

In summary, a driving simulator can be used to study the interaction between the driver and an in-vehicle system in an efficient and risk-free manner. A driving simulator is a valid instrument for this purpose if it has the ability to reproduce the aspects of driving being studied. In particular conclusions on relative effect sizes can be drawn.

5.2.2 Measures of driving behaviour

Driver support systems may result in intended and unintended changes in driving behaviour, which in turn will affect traffic safety and traffic efficiency. Measures of driving behaviour are used to assess such changes in driving performance. These measures mainly focus on the performance on the tactical and operational levels of the driving task (Michon, 1985). One reason to use measures of driving behaviour to evaluate in-vehicle technology, is that they might be related to accident risk. Even if degraded performance does not lead to a crash, it does increase the likelihood of a crash by reducing safe driving tolerances and the ability to recover in the case of unexpected events (Wierwille et al., 1992).

Basically, three categories of driving behaviour measures can be distinguished (Johansson et al., 2004): (1) longitudinal control measures, (2) lateral control measures and (3) event detection measures. Table 5.1 (on page 51) shows some examples of the measures. Note that the enumerations in this section are not exhaustive. Only the most commonly used measures are presented.

(1) The longitudinal control measures can be grouped into two sub-categories: measures of regulating speed and car-following. Speed plays an important role in the chance of becoming involved in an accident as well as in the severity of an accident. Generally, higher speeds will result in a higher accident risk. Aarts (2004) concluded that this relation could probably be best described using a power function: the accident risk increases more as the speed increases. Also speed variation (i.e. speed variance and standard deviation of speed) is assumed to be

related to accident risk. The likelihood of an accident decreases with decreasing speed variations between vehicles (Aarts, 2004). In experimental research, the variation in driving speed of individual drivers is often taken into account to study the extent to which the driver varies his speed (i.e. intra-individual variation), for example as a result of driving with a driver support system. Measures with respect to car-following are related to safety margins, such as time headway and Time-To-Collision (TTC). Vogel (2003) stated that small time headways generate potentially dangerous situations, whereas TTCs indicate the actual occurrences of such situations. Most research particularly focuses on time headways smaller than 1 s, referring to a higher accident risk. However, when driving at short headways, the speed difference is probably smaller compared to driving at longer headways. Consequently, very short time headways (i.e. smaller than 0.5 s) might decrease the accident risk (Hoedemaeker & Janssen, 2000). The TTC can be used to distinguish normal from critical car-following behaviour. Van der Horst (1990) concluded that TTCs smaller than 4 s indicate potentially dangerous situations, whereas TTCs smaller than 1.5 s can be considered critical.

(2) Also the lateral control measures can be grouped into two sub-categories: measures of steering and lane-keeping. Measures of steering reflect steering corrections. An increase in small steering corrections might indicate an increased effort spent on the lateral control task, for example due to a narrow road (Johansson et al., 2004). However, an increase in small steering corrections can also be related to situations in which the driver is distracted by in-vehicle technology. Measures of lane-keeping, such as lateral position and lane exceedings, might imply degraded lateral control and hence, increased accident probability. One of the most commonly used measures when evaluating in-vehicle technology is the variation in lateral position (i.e. SDLP: standard deviation of lateral position). Nilsson et al. (2002) found that the use of driver support systems can increase the SDLP, presumably due to a decreased attention to the driving task. The lateral counterpart to the TTC is the Time-to-Line-Crossing (TLC), developed by Godthelp et al. (1984). They stated that as a rule of thumb TLCs smaller than 1 s indicate an increased risk level.

(3) The event detection measures are concerned with the (in)correct detection of events during driving. Detection performance can be measured to stimuli that are more or less relevant to the driving task, e.g. braking lead cars and suddenly appearing pedestrians. The most commonly used approach is to use lead vehicles or other on-road obstacles as stimuli and braking as the response modality. Also accelerator release and steering avoidance are used as response modalities. For example, Desmond et al. (1998) found that drivers tended to not reclaim control of the driver support system in time during critical situations.

In summary, a great diversity of measures of driving behaviour exists. However, there does not seem to be much consensus on which measures are best suited to evaluation purposes. Rather, the goal of an assessment of an in-vehicle system is often to identify any effects of the system, and thus, a large set of measures is generally used. The HASTE project showed that the following four measures were most discriminating with respect to the evaluation of in-vehicle information systems on driving behaviour: (a) mean speed, (b) steering activity in terms of HFA, (c) minimum time headway and (d) subjective rating of the quality of one's own driving performance (Johansson et al., 2005).

Table 5.1: Measures of driving behaviour

Longitudinal control measures	
Regulating speed	Mean speed
	Standard deviation of speed
	Maximum speed
	Mean acceleration/deceleration
	Maximum acceleration/deceleration
Car-following	Mean distance headway
	Standard deviation of distance headway
	Minimum distance headway
	Mean time headway[1]
	Standard deviation of time headway
	Minimum time headway
	Proportion of time headway < X s
	Minimum Time-To-Collision[2] (TTC)
	Proportion of TTC < X s
Lateral control measures	
Steering	Standard deviation of steering wheel angle
	High Frequency Area[3] (HFA)
	Steering wheel Reversal Rate[4] (SRR)
Lane-keeping	Mean lateral position
	Standard deviation of lateral position
	Lane-changes
	Lane use
	Line crossings
	Minimum Time-to-Line-Crossing[5] (TLC)
	Proportion of TLC < X s
Event detection measures	
Event detection	Response time
	Response distance
	Errors of omission
	Errors of commission

[1] The time headway documented in this thesis is defined as the distance to the lead vehicle from the front bumper of the own vehicle to the rear bumper of the lead vehicle divided by the own current driving speed.
[2] The TTC is the time required for two vehicles to collide if they continue at their present speed and on the same path. The TTC is calculated as the relative distance to a preceding vehicle divided by the relative speed.
[3] The HFA measure is derived from the steering wheel signal by determining the power spectral density function using a Fast Fourier Transformation. Next, the HFA measure is calculated as the energy in the frequency band 0.3-0.6 Hz divided by the energy in the frequency band 0.0-0.6 Hz. Generally, the higher the HFA, the more effort one puts in the steering task.
[4] The SRR is defined as the number of times per unit of time that the steering wheel angle is reversed through a certain angle or gap. Generally, the SRR increases with task demand.
[5] The TLC is defined as the time to cross either lane boundary with any of the wheels of the vehicle if speed and steering wheel angle are kept constant. The TLC reflects a lateral control safety margin.

5.2.3 Measures of mental workload

Mental workload can be expressed by the specification of the amount of information processing capacity that is used for task performance (De Waard, 1996). Measures of mental workload are used to assess the workload that in-vehicle technology might place on a driver. Driver support systems can have a negative effect on safety if they increase mental workload or distract the driver. Sudden increases in mental workload can occur during the interaction of the driver with the in-vehicle system, since the driver has to divide his attention between the system and the primary task of car driving. Even if the system does not require the driver to look on a display, the system may distract by providing information to the driver (e.g. haptic, acoustic feedback) or performing actions that the driver did not expect or initiate (Martens & Van Winsum, 2000). Basically, three categories of mental workload measures can be distinguished (Wierwille & Eggemeier, 1993): (1) task performance measures, (2) physiological measures and (3) self-report measures.

(1) Task performance measures are based on the registration of the participant's capability to perform the main task (e.g. car driving) at an acceptable level. They can be further divided into primary and secondary task performance measures. Primary task performance measures are directly related to the main task. Examples of these measures for car driving are speed, standard deviation of lateral position and standard deviation of steering wheel movements. Reduced primary task performance can indicate mental overload or a reduced driver state. For example, car drivers tended to slow down when the task became more demanding due to the absence of road lighting during darkness (Hogema & Veltman, 2002). An advantage of primary task performance measures is that this method does not interfere with the actual task. A disadvantage is that it can sometimes be insensitive to increased mental workload, since the participant might be able to use additional resources to meet the increased demand and thereby maintain the level of performance. Secondary task performance measures are indirectly related to the main task. They measure the presumed spare or reserve processing capability available while performing the main task. The participant's performance on the secondary task is used to estimate the mental workload of the main task. The advantage of secondary task performance measures is that this method has a high reliability, i.e. it will give consistent scores under given conditions, even with respect to short-lasting variations in mental workload. A disadvantage is that there is a high risk of interference with the actual task. However, the so-called Peripheral Detection Task (PDT) does not have this disadvantage (Martens & Van Winsum, 2000). This measure can be considered a low-level easy-to-automate process that requires little conscious attention. It is based on the participant's manual responses to visual stimuli in the periphery of his field of view. The stimuli can be presented by a LED mounted to a headset (see Figure 5.1). On average each 4 s, with a random variation between 3 s and 5 s, a stimulus is visible during one second. The average reaction times to the appearance of the signals and the percentage of missed signals are used as performance indices. The higher the percentage of missed signals and the longer the reaction times to the signals, the more demanding is the main task and the higher is the mental workload. The PDT proved a sensitive method for assessing variations and peaks in mental workload by measuring the (cognitive) selectivity of attention (Martens & Hoedemaeker, 2001).

Figure 5.1: Driving with the Peripheral Detection Task (PDT)

(2) Physiological measures are derived from the participant's physiology. For example, cardiac functions can be used to measure mental workload. The contraction of the heart is produced by electrical impulses that can be measured in the form of the ECG (Electro Cardio Gram). From the ECG signal several measures can be derived, such as average heart rate and heart rate variability (Mulder, 1992). The average heart rate (HR) can be calculated from the inter-beat interval (IBI, i.e. the time between two peaks in the ECG). For the analysis of average heart rate data, IBI scores are preferred to HR scores, because these scores are more normally distributed in samples and less influenced by trends (De Waard, 1996). By means of spectral analysis, the 0.1 Hz component of the heart rate variability (HRV) can be determined. For the analysis of heart rate variability data, the spectral power values are linearly transformed to obtain a normal distribution of these values. Mental workload has a clear impact on both average heart rate and heart rate variability. The higher the HR score and the lower the HRV score in the 0.1 Hz band, the more mental effort has to be spent (Mulder, 1992). Other physiological measures are for example EEG (electroencephalogram; to measure brain activity), eye fixations, pupil diameter, respiration and blood measures (Martens & Hoedemaeker, 2001). An advantage of this category of workload measures is that they do not require an overt response by the participant. Moreover, the participant cannot directly influence the outcome of this method. Another advantage is that most of the measures can be collected continuously. However, the required specialized equipment and technical expertise, and the critical signal-to-noise ratios can be regarded disadvantageous.

(3) Self-report measures are used to measure the subjectively experienced mental effort. This method is based on the participant's rating of his performance. The NASA Task Load Index (TLX) is a multi-dimensional scale that measures the subjective evaluations of six factors of workload (Hart & Staveland, 1988). The participant is asked to rate his workload on a scale from 0-100 and to rate the relative importance of the different factors. These ratings can be summarized to obtain an overall workload assessment. Also the Rating Scale Mental Effort (RSME) is an example of a self-report measure (Zijlstra, 1993). It is a one-dimensional scale, represented by a vertical line of 15 cm with several anchor points that relate to invested effort (e.g. 'almost no effort' or 'extreme effort'). The participant has to indicate the amount of invested effort on the RSME. The Bartenwerfer activation scale can be used to measure the subjectively experienced activation (Bartenwerfer, 1969). Like the RSME, it is a one-dimensional scale. The anchor points relate to activation states (e.g. 'deep sleep' or 'frightened to death'). The participant is asked to indicate his mental activation during task performance. Self-report measures are mainly suitable for measuring mental workload over longer periods of time, while they are unable to detect short-lasting variations in workload. Advantages of self-report measures are that they require little instrumentation and that the user acceptance is high. A disadvantage is that the ratings may be influenced by factors other than the actual level of load experienced by the participant, such as contextual effects. There is no evidence that multi-dimensional scales such as the TLX are more sensitive to variations in workload than one-dimensional scales such as the RSME (Martens & Hoedemaeker, 2001).

In summary, there are many ways to measure mental workload. The above measures have their strengths and weaknesses with respect to the sensitivity to workload (De Waard, 1996). Therefore, the general advice for researchers is to identify and control as many sources of mental workload as possible. Multiple measures should be used – preferably more than one measure from each category – to draw valid conclusions about the interaction between driver and system and about the driver's state (Wierwille & Eggemeier, 1993; De Waard, 1996).

5.2.4 Measures of user acceptance

User acceptance is considered a prerequisite for the introduction of new in-vehicle technology. Basically, it deals with the question of whether the system under investigation will satisfy the needs and requirements of the users. Generally, potential users are invited to drive with an in-vehicle system (e.g. in a driving simulator), after which they indicate their acceptance of the system by means of questionnaires or interviews.

Two well-known theoretical frameworks for research into (technology) acceptance are the Theory of Planned Behaviour (Azjen, 1991) and the Technology Assessment Model (Davis et al., 1989). Both frameworks try to predict behaviour, such as using a driver support system, by attitudes towards that behaviour. For example, Åberg (2003) used the Theory of Planned Behaviour as a starting point for his research on norms, attitudes and behaviour with respect to Intelligent Speed Adaptation. However, Kantowitz et al. (1997) stated that attitude is often poorly correlated to behaviour. Therefore, they proposed a comprehensive model of the acceptance of innovation, adapted from Mackie & Wylie (1988). The authors suggested that rating scales should be created for the components of acceptance, such as: relative advantage, ease of use, compatibility with other driving activities, safety improvements, relative personal risk and recommendation to others. Besides these measures of acceptance, a lot of other measures are found in literature. Examples are: perceived value, ease of learning, accessibility, availability, trust/liability, compatibility with lifestyle, affordability, social acceptability and satisfaction (Robin-Prévallée et al., 1998; Regan et al., 2002). Another aspect of the acceptance of a driver support system might be the willingness to pay for it. The maximum amount of money a user is willing to pay for the system is an indicator of the value of that system to him. Juster (1966) developed a scale to measure buying intentions. This scale particularly showed good accuracy of predicting car purchases (Day et al., 1991).

Van der Laan et al. (1997) concluded that there are as many methods of assessment of acceptance as there are acceptance studies. Therefore they introduced a simple questionnaire to measure the acceptance of new in-vehicle technology. Acceptance has been operationalized as direct attitudes towards a particular system on nine five-point rating-scale items. These items load on two dimensions: usefulness and satisfaction. Practical aspects are reflected in the usefulness score, while the pleasantness is mirrored in the satisfaction score. The questionnaire was sensitive to differences in opinion about specific aspects of in-vehicle systems, as well as to differences in opinion between different driver groups.

5.3 Effects of driver support systems on the driver

The results from the user needs survey (see Chapter 4) were used to design the so-called Congestion Assistant. This in-vehicle system provides the driver with congestion warnings and haptic feedback before the jam and takes over the longitudinal driving task in the jam. This section discusses the results of earlier research into driver support systems that are related to the functions of the Congestion Assistant. The focus is on the impacts of these systems on the driver in terms of driving behaviour, mental workload and acceptance.

5.3.1 Congestion warnings

Hogema & Göbel (2000) conducted a driving simulator experiment to investigate the effects of in-vehicle and roadside queue warnings on driving behaviour. With the queue warnings, the process of speed reduction started at a larger distance from the tail of the traffic jam. In addition, the maximum decelerations were smaller and the minimum TTCs increased when approaching the queue. However, the in-vehicle warnings did not lead to the same (or better) results than the roadside warnings, although it should be noted that the in-vehicle warnings were only given very near to the tailback, while the roadside warnings were shown at larger distances from the jam.

In another research project on in-vehicle warnings the so-called WARN system was developed (Gensler, 2001). Based on vehicle-vehicle communication, the WARN system received warnings from other traffic, for example vehicles in traffic jams or vehicles broken down standing at the roadside. The impacts of two prototypes of the WARN system on the driver were studied in a driving simulator experiment and a field test (Dahmen-Zimmer et al., 2001). The participants received three warnings from the system: at 1000 m, 500 m and 250 m from the hazard. The warnings were presented on a display with text and icons. Besides, acoustic feedback was given by sound signals or spoken messages. The results from both the driving simulator experiment and the field test revealed a significant speed reduction without hard braking actions with the WARN system when approaching the hazard. It was concluded that together with this speed reduction, a higher attention to the downstream traffic conditions would lead to an increased traffic safety. The acoustic feedback accompanying the visual feedback on the display was regarded necessary. In general, the participants were positive about the WARN system. They thought that the warnings were clear and increasing their safety. Most participants indicated to be willing to pay DM500 (€250) or more for the system.

Within the German research initiative INVENT, the so-called Traffic Performance Assistant (TPA) was designed to make the traffic flow more smoothly and relieve traffic jams (Krautter et al., 2003). The system focused on maintaining high flows in merging sections, damping of stop-and-go waves and dissipating congestion. To this end, detailed information about the current traffic state needed to be available which was provided by vehicle-vehicle communication. The TPA evaluated this information and gave the driver advice (i.e. informing TPA) or adjusted the parameters of an on-board Adaptive Cruise Control (ACC) system (i.e. automated TPA). Krautter et al. (2004) performed a driving simulator experiment to study the effects of the informing TPA on driving behaviour and acceptance. The TPA provided the driver with congestion information on a display (e.g. “congestion ahead, slow down” and “end of congestion, accelerate quickly”). The participants reduced their speed earlier when approaching the traffic jam and drove more smoothly in the jam when driving with the TPA compared to driving without this system. No effects were found for stronger accelerations after the jam. The participants considered the TPA to be beneficial to them and other drivers. The results from the driving simulator experiment were used to adapt the parameters of a car-following model to study the impacts of the TPA on overall traffic performance (Manga et al., 2005).

The Dutch ministry of Transport investigated how tailored information can allow road users to better make choices, and how travelling can be made more effective and more pleasant in the RoadWise (in Dutch: Wijzer op Weg) project. Prior to the field test, the RoadWise system was evaluated in a driving simulator experiment (Hogema, 2005). The system provided the driver with traffic and travel information and with ‘infotainment’ services. When approaching a traffic jam, the system presented several kilometres in advance the information from the Motorway Traffic Management system on a display. This information concerned the messages with respect to dynamic speed limits and possibly blocked lanes. The RoadWise system did not appear to affect the maximum deceleration and the minimum TTC. Furthermore, the system did not lead to a higher mental workload, although merely approaching a traffic jam resulted in a higher workload compared to free driving.

5.3.2 Haptic feedback

The Congestion Assistant in this project uses haptic feedback to slow down the driver when approaching a traffic jam at too high speed, which is a new application of this feature. So far, haptic feedback – also called ‘active gas pedal’ – was particularly applied in Intelligent Speed Adaptation (ISA) systems.

An instrumented car with an active gas pedal was used in field tests in three European countries to study the effects of an in-car speed limiter (Várhelyi & Mäkinen, 2001). The system provided the driver with a counterforce of the gas pedal whenever he tried to exceed the actual speed limit. If necessary, the driver could overrule the system by pressing the pedal harder. The speed limiter revealed a speed-suppressing effect on roads with speed limits ranging from 30 to 70 km/h. Besides, speed variance decreased and time headways increased, indicating safer car-following behaviour. The majority of the participants accepted the speed limiter, especially in built-up areas. However, most participants also reported that driving with the system was more stressing and frustrating than driving without it. Várhelyi et al. (2002) studied the effects of large-scale use of the speed limiter in the city of Lund, Sweden. For a period of 5-11 months, 284 cars were equipped with the system. The results indicated that the system increased compliance with the speed limits. The participants generally experienced the active gas pedal as a support in car driving. However, those who would need it most (e.g. regular speeders), were more negative to the idea. The field test further revealed that technical problems disturbed the positive effects.

Rook & Hogema (2005) studied the effects of a low-force ISA and a high-force ISA on driving behaviour, mental workload and acceptance in a driving simulator. The low-force ISA was easy to overrule and informative in nature with a maximum counterforce of 50 N, while the high-force ISA was more compulsory in nature with a maximum counterforce of 150 N. Both ISA versions reduced the mean free-driving speed on rural roads. The high-force ISA appeared to be more effective than the low-force ISA. The results further suggested an increase of lane-changes and a decrease in time headway when driving with ISA. Compared to driving without ISA, the workload increased most with high-force ISA. Driving with low-force ISA resulted in a workload that hardly differed from driving without ISA. The low-force ISA was more accepted than the high-force ISA: the difference could be attributed to the satisfaction of the system rather than its usefulness. The willingness to have ISA in their own cars showed that 44% of the participants would like to have the low-force ISA compared to 23% wanting the high-force ISA. Apparently, the design of an active gas pedal affects the acceptance of the system considerably.

A field test in Ghent, Belgium with 37 equipped vehicles revealed that haptic feedback led to a reduction in the amount of speeding (Vlassenroot et al., 2007). However, less frequent speeders driving with the system tended to accelerate faster towards the speed limit and drive at this limit, which caused their average speeds to go up. The participants noticed that the active gas pedal assisted them well in keeping the speed limits and that the system increased driving comfort. Fifteen private car drivers chose to keep the active gas pedal after the field test, which was a significant indication of the acceptance of the system.

5.3.3 Automatic congestion driving

Reichardt (1998) stated that the combination of telematics and automated driving opens a new dimension for the future: the driver can focus his attention on office applications while the car takes over the congestion driving task. A driving simulator experiment was conducted to study the hand-over between the system and the driver. At the end of a traffic jam, the system presented a sound signal to demand the driver to take over control. Shortly after the take-over, the lead vehicle braked. The results showed that the participants needed about two seconds to take over control from the system. No differences were found between automatic congestion driving and normal driving with respect to the participants' brake reaction time. It was concluded that there was no evidence of an increased risk for the driver when he was working during automatic congestion driving.

Most research into automatic congestion driving concentrates on the extension of an Adaptive Cruise Control (ACC) system with a Stop & Go functionality. With Stop & Go, the ACC automatically regulates speed and keeps a safe distance to the lead vehicle during stop-and-go traffic. In this way, the driver is relieved from the strain of constantly accelerating and decelerating. Generally, a Stop & Go can be used in an urban environment and on congested motorways. Brook-Carter et al. (2002) conducted a driving simulator experiment to investigate the effects of an urban ACC on driving performance. Participants had to drive with this system during light and heavy traffic in an urban area. The urban ACC consisted of automatic longitudinal control with a desired speed of 64 km/h (i.e. the speed limit of 40 mph), an acceleration range between $-2.5\ m/s^2$ and $+1.0\ m/s^2$ and a desired time headway of 1.5 s. The results revealed that the urban ACC maintained a higher mean speed and a smaller time headway compared to unsupported driving. Thus, the participants were more comfortable at lower speeds and larger headways than those given by the parameters of the system. Driving with the urban ACC led to a reduction in mental workload. This reduction, however, may diminish driver attention and negatively affect safe driving (Young & Stanton, 2002). Indeed, more variation in the lateral position was found, suggesting a reduction of the participant's involvement in the driving task. However, the smaller reaction times to a secondary task when driving with the system were contradictory and indicated positive effects on driver awareness. The participants found the urban ACC relatively easy to learn and easy to use, but they also thought that it would decrease their joy of driving. Moreover, they judged the system in heavy traffic more unpleasant and worthless compared to light traffic. It was concluded that the parameters of the urban ACC should be adjustable to a range in which the driver can set desired speeds and headways to their preferred level of comfort.

Stop & Go was also studied in an urban environment in the STARDUST project (TRG, 2004). To this end, two driving simulator experiments were conducted. The driver could overrule the system at any time by using the accelerator or the brake pedal. The behavioural effects of Stop & Go showed a lower mean speed, a lower variance in speed and shorter start delays, which may be considered an improvement of the traffic flow. No significant changes in time headway, neither mean nor variance, were found. Generally, the participants considered the Stop & Go to be useful, especially in urban areas with dense traffic. After the experiment, the acceptance was higher, although there were also more negative opinions (Tripodi et al., 2003). This is probably because by using the system, the participants could better understand its limits, for example the fixed distance to the lead vehicle or the moderate braking capabilities.

Within the German research initiative INVENT, the so-called Congestion Assistant was designed to support the driver within the low speed segment in non-urban congested areas by giving longitudinal and lateral control (Hummel et al., 2003). Based on sensor data and subjective congestion classifications, an objective classifier of typical traffic congestion situations was made. This classifier served as input for the control algorithm of the Congestion Assistant. Five different prototypes of the system were developed: one was built into a truck and four were built into passenger cars. The little information that is available from the field tests with these vehicles revealed that the participants were positive about the system, expecting it to increase traffic safety and driving comfort (INVENT, 2005). They found driving with the Congestion Assistant pleasant and relaxed, although most participants thought that the system could be further improved. For example, the majority of the participants wanted the system to automatically accelerate after standstill.

5.4 Implications for this research

One of the aims of this research project is to study the impacts of our Congestion Assistant on the driver. This system is not available on the market, which strongly limited the selection of a suitable evaluation methodology. For example, a large-scale field test was impossible. Potential safety risks could manifest during the assessment of the Congestion Assistant. Besides, not all technology of the Congestion Assistant is currently at hand. Therefore, a driving simulator experiment was preferred to a field test with an instrumented vehicle. Using a driving simulator also greatly facilitated the data collection, since most driving performance measures were continuously available.

The results of earlier research discussed in this chapter revealed several effects of driver support systems similar to the functions of the Congestion Assistant. For example, in-vehicle warnings showed speed reductions when approaching a traffic jam. Haptic feedback of ISA systems resulted in a better compliance to the speed limit. The effects of Stop & Go on driving behaviour largely depended on the speed and headway settings. The mental workload with an active gas pedal appeared somewhat higher compared to unsupported driving. However, the results suggested a decrease in mental workload when congestion driving was (partly) taken over by Stop & Go. Generally, the test drivers stated to appreciate the congestion warnings, haptic feedback and automatic congestion driving. The effects of such systems on the driver will in their turn affect traffic performance in general, for example with respect to traffic safety and traffic efficiency.

Following from the literature review, it is expected that the behavioural responses of drivers to the Congestion Assistant will be positive. This expectation was tested by examining the impacts of the Congestion Assistant on driving behaviour, mental workload and acceptance. Not only the assessment of the separate functions was of interest, but also the assessment of the total Congestion Assistant. To our knowledge, no such system – consisting of a combination of informing, assisting and controlling functions – has been evaluated before. To study the impacts of the Congestion Assistant on driving behaviour, several measures related to speed, acceleration, car-following, steering effort and lateral position were taken into account. Measures related to the use of the system were considered as well. Mental workload of driving with the Congestion Assistant was determined by a combination of measures with respect to: (1) task performance: Peripheral Detection Task, (2) physiology: heart rate and (3) self-report: Rating Scale Mental Effort. The acceptance questionnaire of Van der Laan et al. (1997) was used to measure the acceptance of the Congestion Assistant and its functions. In addition, the willingness to buy the Congestion Assistant was measured with the Juster scale (Juster, 1966). The next chapter will discuss the set-up of the driving simulator experiment and the impacts of the Congestion Assistant on the driver.

Chapter 6

Impacts of the Congestion Assistant on the driver

A driving simulator experiment was conducted to investigate the impacts of the so-called Congestion Assistant on the driver in terms of driving behaviour, mental workload and acceptance. This chapter describes the set-up of the experiment and discusses the results. Thirty-seven participants took part in the experiment. They stated to appreciate the Congestion Assistant, although not all functions were equally rated. The observed driving behaviour with the Congestion Assistant showed promising improvements in traffic safety when approaching the traffic jam. Moreover, positive indications of the system on traffic efficiency were found in the jam. The findings of this chapter were used to investigate the impacts of the Congestion Assistant on the traffic flow discussed in Chapter 8.

6.1 Introduction

This chapter focuses on the assessment of the Congestion Assistant with respect to driving behaviour, mental workload and acceptance. For this purpose, a driving simulator experiment was carried out. The Congestion Assistant supports the driver during congested traffic situations on motorways. It consists of the following functions:

- Warning & Information: while driving towards the traffic jam, the driver receives a warning of the traffic jam ahead. While driving in the traffic jam, information about the length of the traffic jam is displayed.
- Active pedal: while approaching the traffic jam, the driver can feel a counterforce of the gas pedal when the speed is too high according to the system.
- Stop & Go: while driving in the traffic jam, the longitudinal driving task is taken over by the system.

Driving with the Congestion Assistant could potentially lead to safer and more efficient driving behaviour. However, this is largely dependent on how drivers will use the system (i.e. in terms of driving behaviour) and their acceptance of it. In this driving simulator experiment hypotheses were tested with respect to behavioural reactions when driving with the Congestion Assistant. The main hypotheses were as follows:

- The driver will be better prepared for the traffic conditions ahead by the Warning function. This could be expressed by earlier and smoother decelerations.
- With the Active pedal, the driver will better anticipate the traffic jam by earlier and smoother decelerations and by safer car-following behaviour.
- The Stop & Go will perform more efficiently and better anticipate leading vehicles than the driver when driving in stop-and-go traffic. This could be expressed by smoother accelerations and decelerations and by car-following at closer headways with less variation.
- The Congestion Assistant – and in particular the Stop & Go – will reduce the driver's mental workload by taking over part of the driving task.
- Respondents to the user needs survey indicated strong needs for support in reduced visibility conditions. The Congestion Assistant will therefore be appreciated more during such situations (e.g. in fog) than during clear sight.
- Participants of the driving simulator experiment were selected from the respondents to the user needs survey. Participants with a positive attitude towards congestion assistance – based on their survey answers – will be more positive about the Congestion Assistant than participants with a negative attitude.

The set-up of the driving simulator experiment is described in the next section, starting with a detailed explanation of the functions of the Congestion Assistant. After that, the results of driving with the system on driving behaviour, mental workload and acceptance are presented. These results are then discussed in the light of the hypotheses stated above. Furthermore, the methodology used is considered. The chapter ends with conclusions.

6.2 Set-up of driving simulator experiment

6.2.1 Congestion Assistant

The Congestion Assistant gives the driver a *Warning* when he is approaching a traffic jam. In this experiment, the warning was presented on a display, which was mounted on the centre console, see Figure 6.1. The first congestion warning is introduced by a sound signal and a corresponding icon lighting up (upper icon, see Figure 6.1). The warning consists of a text message informing the driver about the distance and time towards the traffic jam. This message is updated every half kilometre. The congestion warning is active from 5 km before the traffic jam until the tail of the traffic jam. Furthermore, the Congestion Assistant provides the driver with *Information* when he is driving in the traffic jam. The congestion information is also presented on the display, while the corresponding icon is still lightened up. The information consists of a text message informing the driver about the remaining distance of the traffic jam. This message is updated every half kilometre.

Figure 6.1: Display of the Congestion Assistant on the centre console

When the driver approaches the traffic jam at too high speed, the *Active pedal* of the Congestion Assistant gives him a warning by means of a counterforce of the gas pedal (maximum 50 N). The Active pedal is working from 1.5 km before the traffic jam until the tail of the traffic jam. The activation is introduced by a sound signal and a corresponding icon lighting up on the display (middle icon, see Figure 6.1). The principle of the Active pedal is similar to that of the Intelligent Speed Adaptation system described by Hogema & Rook (2004). It computes a desired acceleration that represents the necessary deceleration for safely approaching the traffic jam. This desired acceleration is calculated based on the distance to the tail of the traffic jam, the current speed and the speed of the last vehicle in the tail of the traffic jam:

$$a_{ac} = \frac{v_j^2 - v^2}{2 \cdot x} \tag{6.1}$$

With

a_{ac}	desired acceleration by Active pedal (m/s^2)
v_j	speed of last vehicle in tail of traffic jam (m/s) (default set at 13.9 m/s ~ 50 km/h)
v	current speed (m/s)
x	distance to tail of traffic jam (m)

The desired acceleration by the Active pedal represents the deceleration needed to obtain the same speed as the last vehicle in the tail of the traffic jam. However, the Active pedal only helps with slowing down and thus gives a counterforce of the gas pedal if the desired acceleration is smaller than a threshold of -0.5 m/s^2. This threshold implies that people driving at 120 km/h will feel a counterforce of the gas pedal around 900 m from the tail of the traffic jam (see Figure 6.2). At that time, the driver's foot is pushed back until a gas pedal position is reached that yields an acceleration equal to the reference acceleration. The driver can overrule the Active pedal by applying more force on the gas pedal. When the desired acceleration of the Active pedal is larger than the threshold, it is assumed that the driver maintains an appropriate speed himself, so that no counterforce of the gas pedal is needed. The Active pedal becomes inactive and the corresponding icon turns off when the tail of the traffic jam is reached.

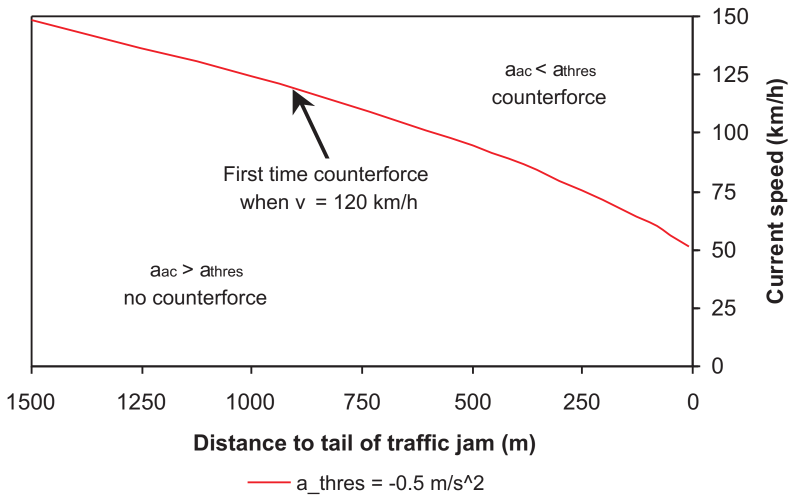


Figure 6.2: Counterforce of gas pedal based on current speed and distance to traffic jam

In the traffic jam, the *Stop & Go* of the Congestion Assistant takes over the longitudinal driving task, including regulating speed, car-following and accelerating (also after standstill). For safety reasons, the driver has to perform the lateral driving task himself to keep him involved in car driving (i.e. 'driver in the loop') (Stanton & Young, 1998). The activation of the Stop & Go is introduced by a spoken message "the Stop & Go will turn on", a sound signal and a corresponding icon lighting up on the display (lower icon, see Figure 6.1). At the end of the traffic jam, the Stop & Go and congestion information are deactivated. This is again introduced by a spoken message "the Stop & Go will turn off". Next, a sound signal is presented and the corresponding icons are turned off. The driver has to take over from the Stop & Go and perform the longitudinal task himself again. The (de)activation of the Stop & Go is delayed if the driver is braking with the brake pedal, hard accelerating (>1 m/s^2) or changing lanes. About 2 s after the spoken messages, the Stop & Go actually becomes (in)active. Preparing the driver for each transition between functions of the Congestion Assistant by sound signals, spoken messages and icons is expected to reduce the negative effects of so-called 'task switching' (e.g. increase of reaction time) (Monsell, 2003).

Table 6.1 shows the features of the Stop & Go. The Stop & Go is expected to be able to deal with all traffic situations (e.g. sudden cut-ins). Therefore, the maximum acceleration was set at +2 m/s^2, while the maximum deceleration was set at -9 m/s^2. The driver could not overrule the Stop & Go. So if the pedals were used, these signals were being ignored by the Stop &

Go. However, the pedals moved with the actions of the Stop & Go, so that the driver could feel the reaction of the system. The algorithm used was to a large extent based on a Stop & Go algorithm studied by De Kok et al. (2004). The reader is referred to Chapter 8 for the equations.

Table 6.1: Main features of the Stop & Go

Feature	Stop & Go
Speed range	0-70 km/h
Intended speed	70 km/h
Time headway setting	1.0 s
Minimum distance headway (at standstill)	3 m
Maximum acceleration	$+2$ m/s^2
Maximum deceleration	-9 m/s^2
Automatic 'go'	yes
Overrulable	no
Sensor range	200 m

It is assumed that the Congestion Assistant receives information about the state of the traffic flow (e.g. by means of vehicle-vehicle and vehicle-infrastructure communication), so that it can provide the driver with the appropriate support function. However, to simplify things in this driving simulator experiment, a static traffic jam with a fixed start and end was created. The functions of the Congestion Assistant were programmed to switch on or off at established points during the experimental runs (see 'sound signals' in Figure 6.3). The driver was not able to (de)activate (functions of) the Congestion Assistant himself.

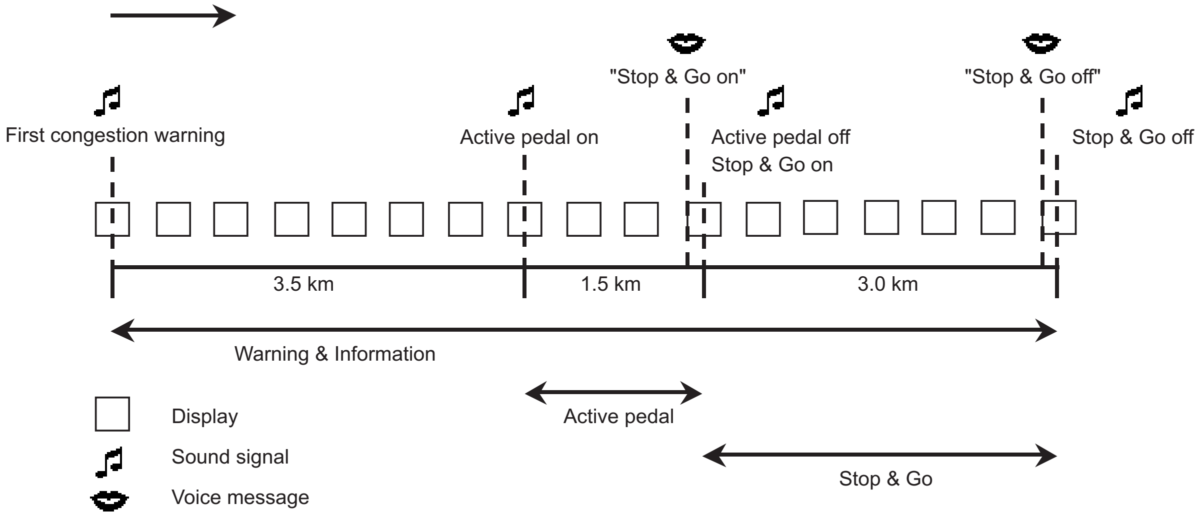


Figure 6.3: Schedule of visual and acoustic feedback of the Congestion Assistant

6.2.2 Experimental conditions and scenarios

The driving simulator experiment was designed to investigate the impacts of the Congestion Assistant on driving behaviour, mental workload and acceptance. The impacts were studied during normal visibility and in fog with a sight distance of 80 m. The fog condition was included, because respondents to the user needs survey indicated strong needs for help in reduced visibility situations. The experimental conditions varied with respect to System (with versus without Congestion Assistant) and Visibility (normal versus fog). This resulted in the following four conditions:

1. Without Congestion Assistant during normal visibility
2. With Congestion Assistant during normal visibility
3. Without Congestion Assistant in fog
4. With Congestion Assistant in fog

Each participant completed four experimental runs corresponding to the four conditions. To avoid order and learning effects, a Latin square design was used to randomize the order of the conditions.

The test road environment consisted of a motorway with a speed limit of 120 km/h. The motorway was based on 2x2 traffic lanes and shoulders according to the Dutch design guidelines (CROW, 1992). The road was mainly straight with a few gentle curves. Approximately 10% of the traffic volume on the right lane consisted of trucks and buses. Each participant encountered a traffic jam during an experimental run. This jam was created by simply ‘telling’ the simulated traffic at what speed it had to drive. For example, vehicles had to slow down when approaching the jam (i.e. 50 km/h at the tail), drive in a stop-and-go mode in the jam (i.e. 0-50 km/h) and accelerate when leaving the jam (i.e. towards 100-120 km/h). Furthermore, extra vehicles were added during the run to gradually increase the traffic flow. For the fog condition, a constant visibility setting of 80 m was used, which can be regarded as dense fog. When driving in fog, drivers behave differently than during driving in clear sight. To come close to reality, the behaviour of the simulated traffic was altered in line with the findings of Hogema & Van der Horst (1994). For example, it was assumed that drivers of a passenger car would drive at a speed of approximately 100 km/h in fog (in contrast to 120 km/h during normal visibility).

Each experimental run had a length of 15 km and was divided into five traffic scenarios. Table 6.2 shows these scenarios, including the type of support from the Congestion Assistant when driving with the system.

Table 6.2: Traffic scenarios in driving simulator study

Scenario	Length	Location	Support from Congestion Assistant
Start	5 km	Far before jam	No support
Section 1	3.5 km	Before jam	Warning
Section 2	1.5 km	Just before jam	Warning and Active pedal
Section 3	3 km	In jam	Information and Stop & Go
Section 4	2 km	After jam	No support

The five traffic scenarios can be further described as follows:

- Start: the participants started on the right lane of the motorway at a speed of approximately 120 km/h during normal visibility or 100 km/h in fog (‘flying’ start). After this, they could choose their own speed, headway, lane, et cetera. At the end of this scenario, the vehicle density increased. The traffic jam was still far ahead of the participants.
- Section 1: at the beginning of this scenario, the participants with the Congestion Assistant received the first congestion warning on the display. Otherwise, no information about the traffic jam at hand was given. The vehicle density further increased as the traffic jam came closer.

- Section 2: during this scenario, the participants with the Congestion Assistant felt a counterforce of the gas pedal when they were approaching the tail of the traffic jam at too high speed according to the system. The congestion warning was still displayed. No information or assistance was provided in the runs without the Congestion Assistant. The vehicle density further increased as participants were almost entering the traffic jam.
- Section 3: this scenario consisted of the traffic jam with vehicles on both lanes driving in stop-and-go mode. The Congestion Assistant took over the longitudinal driving task from the participants and displayed information about the length of the traffic jam. Without the system, the participants had to drive in congestion themselves and received no congestion information.
- Section 4: at the beginning of this scenario, the participants were leaving the traffic jam. Participants driving with the Congestion Assistant had to take over control from the Stop & Go function. All vehicles accelerated again and the vehicle density decreased.

6.2.3 Driving simulator

The experiment was conducted in TNO’s advanced driving simulator (see Figure 6.4). The participant was seated in a BMW 318i mock-up that was placed on a motion base with six degrees of freedom. The mock-up was fitted with original controls, such as pedals and steering wheel, and automatic transmission. The participant watched a large radial screen on which the road and traffic environment was projected. Sounds of surrounding traffic and of the simulator car were presented as well. The experiment leader was seated in a supervisor room next to the mock-up room, where he had access to the control system. He could watch the mock-up room and the participant’s face by means of a video system. Communication with the participant was possible by means of an intercom.

Figure 6.4: The TNO driving simulator

The driving simulator consisted of the following subsystems:

- The mock-up: a BMW 318I with automatic transmission, left seated driver and normal controls. Feedback of steering forces was given to the driver by means of an electrical torque engine.
- The vehicle model computer: for the calculation of the momentaneous position and heading of the simulated vehicle (update frequency 360 Hz). In the current experiment, an automatic gearshift was applied. The vehicle model used Simulink for the model and C++ for the communication with the other subsystems.

- The supervisor computer: for the communication with both the experiment leader and the other subsystems, the control and monitoring of the experiment, data storage, controlling the behaviour of other traffic, et cetera.
- The computer generated image system: a PC based visual system (DELL Dual processor with NVIDIA Quadro 3400 graphic cards) that generated real-time images with a refresh frequency of 60 Hz. The scene manager used VEGA software. C++ was used for the control of VEGA and the communication with the other subsystems. Three high-resolution (1280 x 1024) DLP projectors projected the images on a radial screen in front of the mock-up with a 120^o horizontal and 30^o vertical field of view. Rearview mirrors were simulated by means of separate LCD displays.
- The sound generator system: a sampled sound system using an AKAI S3200 sampler. Loudspeakers in and around the mock-up reproduced the noise of both the simulated vehicle (engine, wind and tyres) and the surrounding traffic generated by the sound system.
- The moving base system: a six degrees of freedom MOOG 2000 E hexapod motion platform with the associated control equipment. Only the mock-up was placed on the platform; the video projectors and the projection screen were stationary.

6.2.4 Participants and procedure

A total of 37 participants took part in the driving simulator experiment. These participants were selected from the respondents who completed the user needs survey described in Chapter 4. Based on their answers, two groups of participants were formed: one group with a positive attitude towards congestion assistance and one group with a negative attitude. Participants with a positive attitude indicated a great need for the car giving warnings for downstream traffic conditions, the car automatically maintaining speed and distance in traffic jams and the ideal system providing support with congestion driving on motorways. Participants with a negative attitude did not indicate these needs. Other selection criteria were: possessing a driver’s license for more than 5 years, driving at least three times a week, driving more than 10.000 km a year, being between 25 and 60 years old and having no motion sickness. The average age of the participants was 43 years. Table 6.3 shows some personal characteristics of the participants.

Table 6.3: Personal characteristics of participants (n = 37)

Characteristic	**Participants**
Gender	
Male	81%
Female	19%
Age	
Younger (18-44 years)	57%
Older (>44 years)	43%
Attitude	
Positive	59%
Negative	41%

Prior to the driving simulator experiment, the participants received a verbal outline of the research. Next, they signed a form of informed consent, completed several questionnaires and read information about the Congestion Assistant. One experimental session took one morning or afternoon. Two participants participated in each experimental session. While one participant was driving, the other participant completed one or more questionnaires and could rest. To get acquainted with the driving simulator and the Congestion Assistant, each participant started with a training run that took 7 minutes. Then, during 3 minutes, the heart rate of the participants was measured while they were sitting in the simulator doing nothing. After that, taking turns, the participants completed the four experimental runs that lasted 15-20 minutes each. They were told to drive like they would normally do in similar situations. The participants were paid for their participation.

6.2.5 Data collection and analysis

Several measures were selected to study the impacts of the Congestion Assistant on driving behaviour, mental workload and acceptance. Moreover, these measures were used to answer the hypotheses mentioned in Section 6.1.

Driving behaviour

The following measures of driving behaviour were taken into account:

- Speed: mean and standard deviation (SD)
- Acceleration: acceleration (>0 m/s^2: mean, max), deceleration (<0 m/s^2: mean, max)
- Car-following: time headway (mean, cumulative distribution, min, SD), Time-To-Collision (TTC) (min)
- Steering effort: High Frequency Area (HFA)
- Use of the Congestion Assistant (e.g. frequency of overruling the Active pedal, reaction time of accelerating after deactivation of Stop & Go)

The driving simulator stored the data with a frequency of 10 Hz. Because the functions of the Congestion Assistant were active in different road sections, the measures above were calculated for these sections (except for the measures regarding the use of the Congestion Assistant). Note that the standard deviations of speed and time headway concern the extent to which a participant varies his speed and time headway.

Mental workload

The participant's mental workload during driving was measured in three ways. First, physiological measures with respect to heart rate were used. The participants had a heart rate monitor on to determine the ECG signals. Average heart rate (HR) and the 0.10 Hz component of the heart rate variability (HRV) were calculated. The data was measured for segments (much) longer than 30-40 s, so the data can be considered robust (Mulder, 1992). Changes in HR and HRV during the experimental runs might be of a rather short duration. Therefore, the sliding windows technique was used with a window of 40 s and a time step of 10 s. Second, the participants had to perform a secondary task – the Peripheral Detection Task (PDT) – while driving. The participants had to wear a headband with a red light stimulus attached to it. As soon as the participant detected the stimulus, he had to respond by pressing a micro switch that was attached to the index finger of the right hand. If a reaction was not detected within 2 s from the onset of the stimulus, this was coded as a missed signal. The average reaction times to the appearance of the signals and the percentage of missed signals were used as performance indices. The third measure of mental workload concerned the Rating Scale Mental Effort (RSME) (Zijlstra, 1993). After each experimental run, the participants had to fill in this checklist by marking the point that represented their perceived invested mental effort (see Appendix C).

In summary, the following measures of mental workload were collected:

- Average heart rate (HR)
- Heart rate variability (HRV)

- Reaction time to PDT signals
- Percentage of missed PDT signals
- RSME score

Acceptance
The acceptance questionnaire developed by Van der Laan et al. (1997) was used to measure the perceived usefulness and satisfaction of the Congestion Assistant. The participants had to fill in checklists before driving, after driving with the system during normal visibility and after driving with the system in fog. Each time four checklists had to be completed: one checklist for the total system and one checklist for each function of the system (i.e. Warning & Information, Active pedal, Stop & Go). An example of the checklist is shown in Appendix D.

The Juster scale (Juster, 1966) was used to measure the willingness to buy the Congestion Assistant. The participants filled in this questionnaire after the experimental run with the Congestion Assistant during normal visibility. They had to assess the probability of buying the Congestion Assistant at the price of €1500, considering they would buy a new car (see Appendix E).

Hence the measures of user acceptance were:
- Scores on the Van der Laan scale
- Score on the Juster scale

Analyses
Differences in driving behaviour, mental workload and acceptance due to the Congestion Assistant were statistically analysed. Analysis of variance (ANOVA) for repeated measurements was used for most analyses. This statistical test examines the equality of means and is appropriate when all subjects or cases of a sample are measured under a number of different conditions. These conditions are represented by the within-subject factors being a set of variables for each group of measurements. The between-subject factors divide the sample into groups (e.g. male versus female). In this experiment, effects of both the within-subject factors and the between-subject factors were assessed by investigating main effects and two-way interactions. Tukey post-hoc tests were used to find out which groups differed from each other. When $p<0.05$, the results were considered to be statistically significant. The vertical bars in the figures of Section 6.3 denote 95% confidence intervals. Before running the ANOVA tests, histograms were examined and Kolmogorov-Smirnov tests were performed to check whether the variables were normally distributed. All variables revealed to follow a normal distribution ($p<0.05$), except for the percentage of missed PDT signals. For this variable, the Friedman test was used, a non-parametric test that compares the means of three or more related groups.

For the analysis of driving behaviour, the following within-subject factors were used:
- Visibility: 2 levels (normal, fog)
- System: 2 levels (without, with)
- Section: 4 levels (far before, before, in, after jam)

For the analysis of mental workload, the following within-subject factors were used:
- Run: 5 levels (rest, normal & without, normal & with, fog & without, fog & with)
- Visibility: 2 levels (normal, fog)
- System: 2 levels (without, with)
- Section: 4 levels (far before, before, in, after jam)

For the analysis of acceptance, the following within-subject factors were used:

- Experience: 3 levels (before, after normal, after fog)
- Function: 3 levels (warning & information, active pedal, stop & go)
- Dimension: 2 levels (usefulness, satisfaction)

The between-subject factor Attitude (positive, negative) was used in all repeated measures ANOVAs to examine the relations between the perceived needs for congestion assistance and driving behaviour, mental workload and acceptance. Because the moving base of the driving simulator broke down halfway the experiment, the factor Motion (without, with) was also included as a between-subject factor in the analyses of driving behaviour and mental workload.

The data were stored with a frequency of 10 Hz, which sometimes led to rather large accelerations and decelerations. Therefore, accelerations over +5 m/s^2 and decelerations below -10 m/s^2 were replaced by +5 m/s^2 and -10 m/s^2 respectively. To represent car-following behaviour, the analyses on car-following used only data from samples with a time headway of 5 s or less. The Kolmogorov-Smirnov test was used to detect differences in the shape of the cumulative distributions of time headway. When the difference between observed cumulative distributions for two groups was significantly large, these two distributions were considered different. The test was applied to the four conditions within each section. This means that per section, six comparisons between two conditions were made. For these comparisons, a more conservative p-level was used, namely $p<0.01$. The data concerning the minimum TTC were not restricted (e.g. bounded by a certain threshold), so that the values ranged from almost 0 s to over 1000 s. Instead of conducting ANOVA tests, the percentages of a minimum TTC below 4 s and 20 s were studied.

Descriptive statistics were conducted to gain more insight into the willingness to buy the Congestion Assistant. An independent samples T test with Attitude (positive, negative) and the Juster score was conducted to investigate the relations between the perceived needs for congestion assistance and the willingness to buy the Congestion Assistant. Pearson’s correlation coefficients were used to study the relations between the acceptance of the Congestion Assistant and the willingness to buy this system by correlating the Van der Laan scores with the Juster score.

6.3 Results

6.3.1 Driving behaviour

General

Each participant completed four experimental runs corresponding to the four conditions based on System (without, with) and Visibility (normal, fog). Data was collected for 37 (participants) x 4 (runs) = 148 runs. However, not all data appeared to be useful. During eight runs, participants did not encounter a traffic jam, which resulted in ‘wrong’ data in the corresponding road section (section 3). These data were regarded as missing values. Besides, the simulation accidentally stopped while driving in the traffic jam during five runs, which resulted in no data in the subsequent road section (section 4). Most data files contained only these missing values, which accounted for 2.2% of all data. The data files with respect to car-following included more missing values. This was mainly due to using data from samples with a time headway of 5 s or less. Since the statistical approach required complete data sets per participant, performing the analyses with files containing missing values would lead to results based on fewer participants (e.g. 9 instead of 37). Therefore, missing values were replaced by the means of the variables concerned. It was considered a legitimate reason to minimize the loss of data in the statistical analysis (Carriere, 1999).

Each run included a traffic jam. The tail of this traffic jam had to be encountered after about 10 km from the start independent of the driving lane. The traffic jam had a length of 3 km, so the participants had to leave the traffic jam after about 13 km from the start. The functions of the Congestion Assistant were programmed to switch on or off at fixed points. During the test runs, no problems occurred. However, during the experimental runs, most participants encountered the tail at a larger distance from the start. Besides, some participants could leave the traffic jam earlier, for example because there was only a queue on one traffic lane instead of on both lanes. This affected the data analysis concerning the road sections before, in and after the traffic jam (section 2 to 4). To better represent stop-and-go traffic, it was decided to replace the original data for driving in the traffic jam (section 3) with data from samples with a speed of 50 km/h or less. All statistical analyses were performed with this updated dataset. More information about implications of the appearance of the traffic jam on the results can be found in Section 6.4.2.

Speed

The results concerning the *mean speed* revealed an interaction effect between Visibility and System [F(1,33) = 11.56, p<0.01], see Figure 6.5. During normal visibility, the mean speed with the Congestion Assistant was lower than without the system. However, the Congestion Assistant did not affect the mean speed in fog. The mean speed during normal visibility was higher than in fog, regardless of driving with the system.

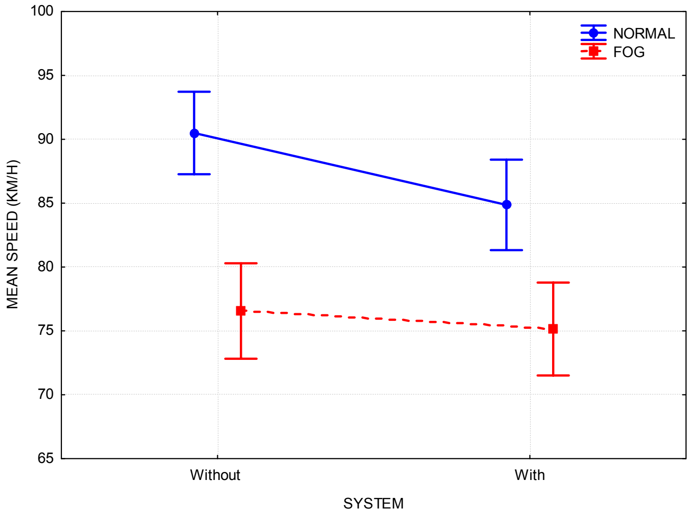


Figure 6.5: Mean speed as a function of Visibility and System

Figure 6.6 shows the interaction effect between System and Section on the mean speed [F(3,99) = 32.39, p<0.001]. The mean speed with the Congestion Assistant was lower than without the system when approaching the traffic jam (section 2, due to Active pedal). In the other road sections, the Congestion Assistant did not affect the mean speed.

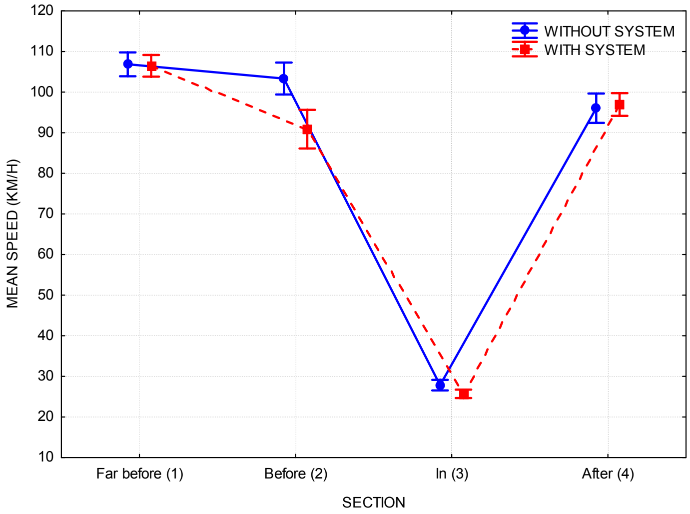


Figure 6.6: Mean speed as a function of System and Section

Furthermore, an interaction effect between Visibility and Section on the mean speed was found [F(3,99) = 55.74, p<0.001]. The mean speed during normal visibility was higher than in fog, except for driving in the traffic jam (section 3). In this section, similar speeds were found, regardless of visibility. The speed choice in the traffic jam depended rather on the stop-and-go traffic in this section than on the visibility conditions.

The results concerning the *standard deviation of speed* revealed an interaction effect between System and Section on the standard deviation of speed [F(3,99) = 10.44, p<0.001], see Figure 6.7. The standard deviation of speed with the Congestion Assistant was larger than without the system when approaching the traffic jam (section 2). This can be explained by the fact that in this section the Active pedal gradually reduced the speed (e.g. from 120 to 50 km/h), which resulted in a larger standard deviation of the driver's speed. On the contrary, when driving without the Congestion Assistant the driver continued driving with a high speed until noticing the traffic jam. The Congestion Assistant did not affect the standard deviation of speed in the other road sections.

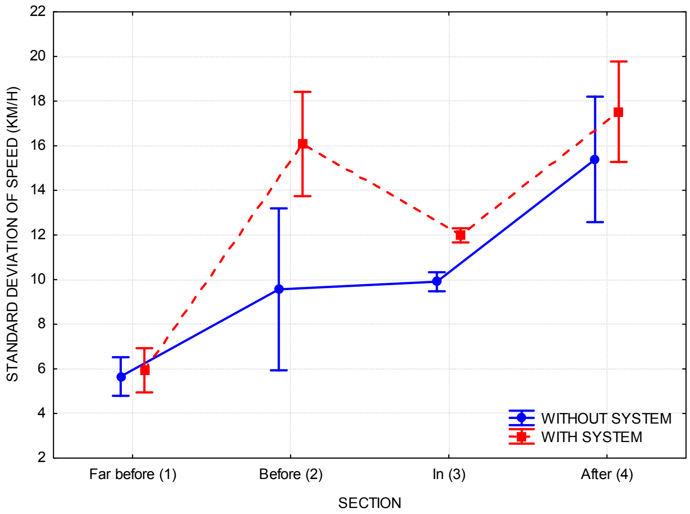


Figure 6.7: Standard deviation of speed as a function of System and Section

In addition, a main effect of Visibility on the standard deviation of speed was found [F(1,33) = 5.80, $p<0.02$]. The standard deviation of speed during normal visibility was larger (12.1 km/h) than in fog (11.1 km/h).

In summary, the impacts of the Congestion Assistant on speed were the following:

- During normal visibility, the mean speed with the Congestion Assistant was lower than without this system
- Due to the Active pedal, the participants reduced their speed and drove with a less constant speed when approaching the traffic jam

Acceleration

The results concerning the *mean acceleration* revealed an interaction effect between System and Section [F(3,99) = 13.78, $p<0.001$], see Figure 6.8. The Congestion Assistant led to a lower mean acceleration in the traffic jam (section 3) than without this system. So the Stop & Go of the Congestion Assistant accelerated less hard in the traffic jam than drivers without the system did. On the contrary, the mean acceleration with the system was higher after the traffic jam (section 4), although this result was found to be affected by the appearance of the traffic jam (see also Section 6.4.2).

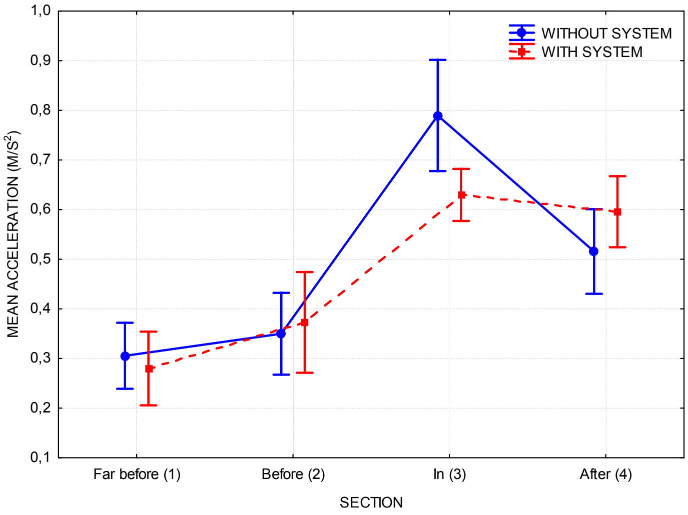


Figure 6.8: Mean acceleration as a function of System and Section

The results concerning the *maximum acceleration* revealed an interaction effect between System and Section on the maximum acceleration [F(3,99) = 27.57, $p<0.001$]. Comparable to the mean acceleration, Figure 6.9 shows that the maximum acceleration with the Congestion Assistant was lower than without this system in the traffic jam (section 3) and higher after the traffic jam (section 4). Thus, drivers speeded up with higher maximum accelerations in the traffic jam than the Stop & Go of the Congestion Assistant did. But after the traffic jam, drivers with the Congestion Assistant accelerated harder than drivers without this system. However, this result was found to be affected by the appearance of the traffic jam (see also Section 6.4.2).

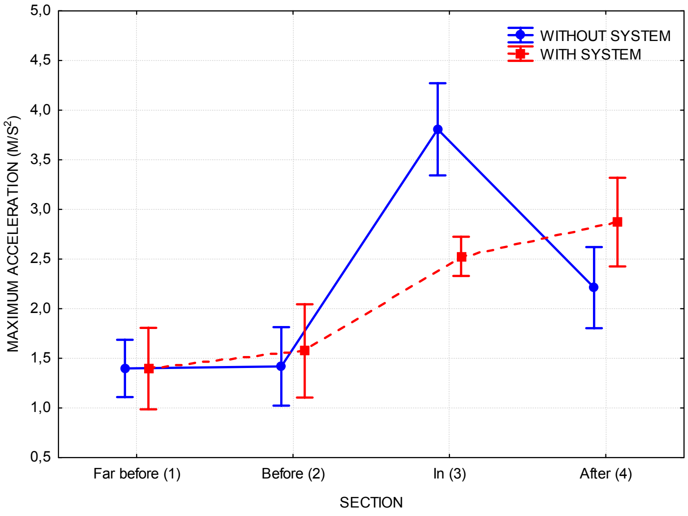


Figure 6.9: Maximum acceleration as a function of System and Section

Furthermore, a main effect of Visibility on the maximum acceleration was found [F(1,33) = 6.06, $p<0.05$]. The maximum acceleration in fog (2.22 m/s^2) was higher than during normal visibility (2.06 m/s^2).

The results concerning the *mean deceleration* revealed an interaction effect between System and Section [F(3,99) = 21.78, $p<0.001$], see Figure 6.10. The Congestion Assistant led to a lower mean deceleration level in the traffic jam (section 3) than without this system. So the Stop & Go of the Congestion Assistant braked less hard in the traffic jam than drivers without the system did.

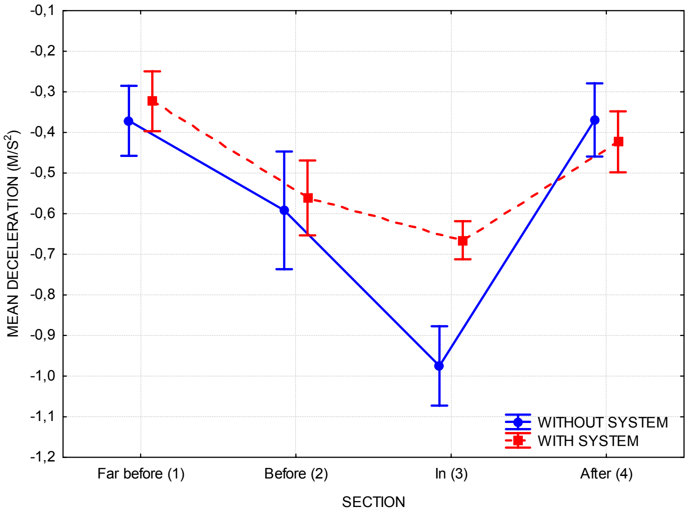


Figure 6.10: Mean deceleration as a function of System and Section

The results concerning the *maximum deceleration* revealed a main effect of System [F(1,33) = 12.07, $p<0.001$]. The maximum deceleration level with the Congestion Assistant was lower (-2.50 m/s^2) than without this system (-2.87 m/s^2). So drivers tended to brake harder when they were not driving with the Congestion Assistant.

In addition, a main effect of Section on the maximum deceleration was found [F(3,99) = 53.33, p<0.001]. The maximum deceleration level was highest in the traffic jam (section 3) (-4.38 m/s^2), while drivers did not brake very hard far before (section 1) (-1.95 m/s^2) and after the traffic jam (section 4) (-1.81 m/s^2).

In summary, the impacts of the Congestion Assistant on acceleration were the following:

- Generally, the maximum deceleration level with the Congestion Assistant was lower than without this system
- The Stop & Go showed smoother acceleration and deceleration behaviour in the traffic jam compared to unsupported driving

Car-following

The results concerning the *mean time headway* revealed an interaction effect between System and Section [F(3,99) = 32.77, p<0.001], see Figure 6.11. When driving in the traffic jam and leaving the traffic jam (sections 3 and 4), the mean time headway with the Congestion Assistant was smaller than without the system. However, the Congestion Assistant did not affect the mean time headway when driving (far) before the traffic jam (sections 1 and 2).

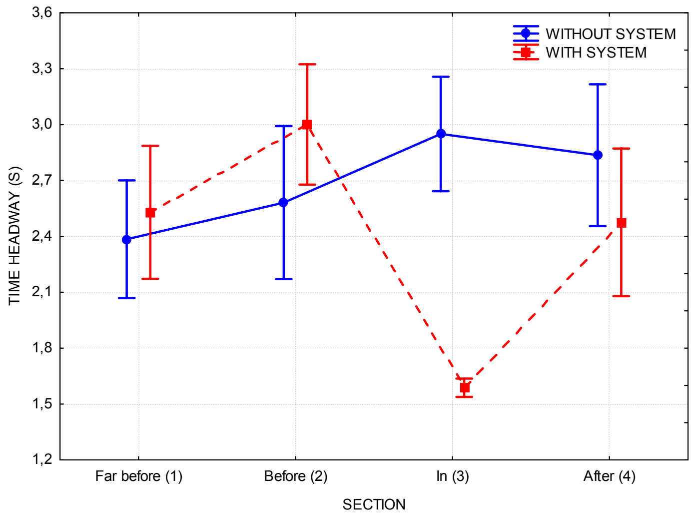


Figure 6.11: Mean time headway as a function of System and Section

The *cumulative distributions of time headway* showed differences between the time headways before and in the traffic jam (sections 2 and 3) [p<0.01]. Figure 6.12 (a) shows that when approaching the traffic jam during normal visibility, about 55% of the time headways were below 2 s when driving without the Congestion Assistant, whereas this was about 20% when driving with the system. In fog, these percentages were about 25% when driving without the Congestion Assistant and about 20% when driving with the system. Evidently, the Active pedal of the Congestion Assistant led to larger time headways when approaching the traffic jam, especially during normal visibility. However, in the traffic jam, about 25% of the time headways were below 2 s when driving without the Congestion Assistant, whereas this was about 80% when driving with the system, regardless of the visibility conditions, see Figure 6.12 (b). So the Stop & Go of the Congestion Assistant led to smaller time headways in the traffic jam.

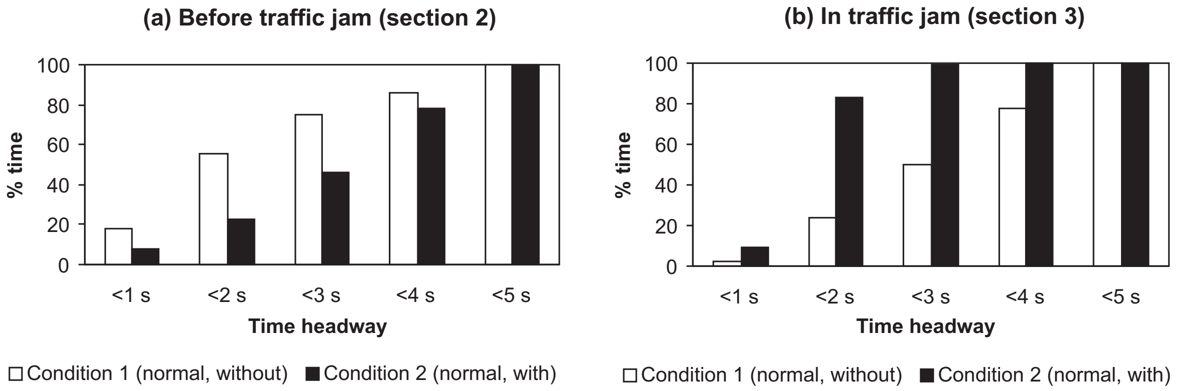


Figure 6.12: Cumulative distributions of time headway (a) before the traffic jam and (b) in the traffic jam without the Congestion Assistant (condition 1) versus with this system (condition 2) during normal visibility

No effects of the Congestion Assistant on the *minimum time headway* were found. Thus, similar time headways were found in each section, regardless of driving with or without the Congestion Assistant.

The results concerning the *standard deviation of time headway* revealed an interaction effect between System and Section [F(3,99) = 17.09, p<0.001], see Figure 6.13. When driving in the traffic jam (section 3), the standard deviation of time headway with the Congestion Assistant was smaller than without the system (due to the Stop & Go).

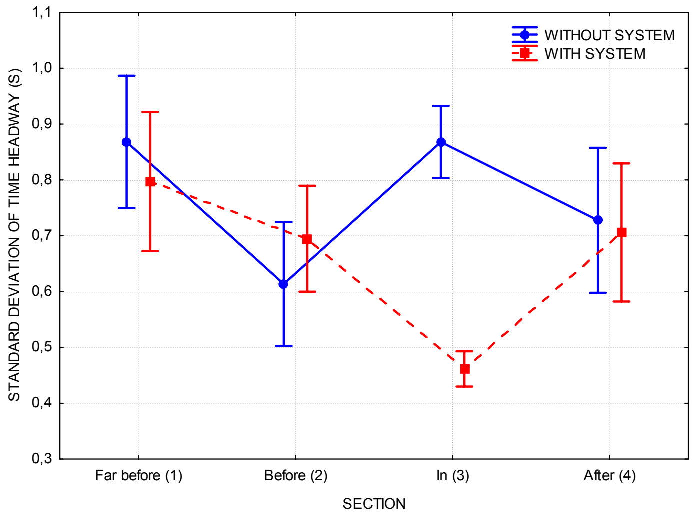


Figure 6.13: Standard deviation of time headway as a function of System and Section

In addition, the Congestion Assistant affected the percentages of a *minimum TTC* below a certain threshold, regardless of the visibility conditions. When approaching the traffic jam, the percentages of a minimum TTC below 20 s with the Congestion Assistant (on average: 39.2%) were lower than without this system (83.8%), indicating safe following situations due to the Active pedal of Congestion Assistant. When driving in the traffic jam, the percentages of a minimum TTC below 4 s with the system (56.8%) were higher than without (31.1%). Generally, minimum TTCs below 4 s indicate potentially dangerous following situations. However, it is not clear whether this also applies to systems that (partly) take over the driving task, such as the Stop & Go of the Congestion Assistant. For example, automating the car-following task during congestion can eliminate possible human errors during this driving task. When leaving the traffic jam, the percentages of a minimum TTC below 20 s with the system (64.9%) were higher than without (50.0%), indicating less safe following situations after having driven with the Congestion Assistant.

In summary, the impacts of the Congestion Assistant on car-following were the following:

- Due to the Active pedal, the participants showed safer behaviour when approaching the traffic jam expressed by larger time headways and TTCs
- The Stop & Go resulted in smaller time headways and TTCs, but also a more constant time headway in the traffic jam compared to unsupported driving
- When leaving the traffic jam, the participants that had driven with the Congestion Assistant showed less safe behaviour expressed by smaller time headways and TTCs

Steering effort

The results concerning the *High Frequency Area (HFA)* revealed an interaction effect between System and Section [F(3,99) = 24.49, p<0.001], see Figure 6.14. The HFA with the Congestion Assistant was higher than without the system when driving before the traffic jam (section 2) and smaller when driving in the traffic jam (section 3). So the Active pedal of the Congestion Assistant led to an increased steering effort when approaching the traffic jam, while the Stop & Go resulted in a decreased steering effort when driving in the traffic jam. However, this former result was found to be affected by the appearance of the traffic jam (see also Section 6.4.2).

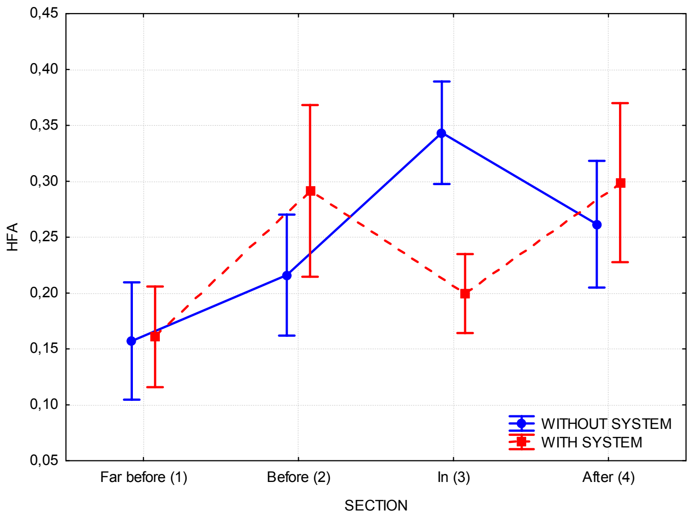


Figure 6.14: HFA as a function of System and Section

In summary, the Stop & Go of the Congestion Assistant led to a decreased steering effort in the traffic jam.

Use of the Congestion Assistant

The use of the Congestion Assistant was investigated with respect to the Active pedal and the Stop & Go. The results on the Active pedal concern the first time that participants felt the counterforce of the gas pedal and the number of times that participants overruled the Active pedal. Table 6.4 shows the descriptive statistics for the first time that participants felt the *counterforce* of the gas pedal. A distinction was made between the two visibility conditions.

Table 6.4: First time counterforce given by Active pedal (distance to tail of traffic jam in m)

	Normal	**Fog**
Mean	760	462
SD	239.7	201.6
Min	17.1	17.5
Max	1315	840

All participants felt a counterforce of the Active pedal at some point before the traffic jam. Thus, no one was slowing down without triggering the Active pedal. Generally, participants experienced the first time of counterforce when they were about 500-700 m away from the traffic jam, although this distance varied a lot between the participants.

For calculating the number of times that participants *overruled* the Active pedal, a counterforce of at least 5% was used as a threshold. It was assumed that participants would feel this amount of counterforce and that this threshold would eliminate noise in the data. Table 6.5 shows the descriptive statistics for overruling the Active pedal during normal visibility and in fog.

Table 6.5: Number of times that participants overruled the Active pedal

	Normal	**Fog**
Mean	2.5	1.8
SD	1.74	1.36
Min	0	0
Max	8	6

On average, the participants overruled the Active pedal two times when approaching the traffic jam. Seven participants did not overrule the Active pedal at all, while one participant overruled it eight times (i.e. maximum).

The results on the Stop & Go concern the number of times that participants used the gas and brake pedal during the Stop & Go mode and the reaction times that participants needed to release or press the gas pedal when the Stop & Go switched on or off. Table 6.6 shows the descriptive statistics for the number of times using the *gas and brake pedal* during the Stop & Go mode. Note that this ‘overruling’ had no effect on the driving behaviour, because the Stop & Go ignored these signals. A distinction was made between the two visibility conditions (normal, fog).

Table 6.6: Number of times that participants used gas or brake pedal during Stop & Go

	Using gas pedal		**Using brake pedal**	
	Normal	*Fog*	*Normal*	*Fog*
Mean	1.5	2.0	0.2	0.2
SD	1.56	2.00	0.46	0.50
Min	0	0	0	0
Max	7	7	2	2

It can be seen that in general participants used the gas pedal about two times during the Stop & Go mode. The brake pedal was used not nearly as much. There was no difference between the number of times using the gas or brake pedal in the two visibility conditions. The gas pedal was used more often than the brake pedal during the Stop & Go mode. Possibly, participants would like to accelerate harder in the traffic jam than the Stop & Go did. For example, the participants remarked that they would like to be able to overrule the system, for example to accelerate when changing lanes.

Participants needed a *reaction time* to release or press the gas pedal when the Stop & Go switched on or off. The activation of the Stop & Go was introduced by a spoken message. Five participants already released the gas pedal before the end of this message. Thus, these persons handed over the control of their vehicle to the Stop & Go too early. More than half of the participants still had their foot on the gas pedal when the Stop & Go took over the longitudinal driving task. Possibly, people wanted to check the system's working first before releasing the pedal (i.e. trust in system). Also the deactivation of the Stop & Go was introduced by a spoken message. Seven participants already used the gas pedal before the end of this message. Thus, these persons took over the control of their vehicle from the Stop & Go fairly in time. Around one third of the participants did not have their foot on the gas pedal when the Stop & Go switched off. These people needed a reaction time on top of the time between the spoken message and the Stop & Go actually turning off (which was about 2 s) to press the pedal. More than 80% of the participants used the pedal within 1 s. The mean reaction time of taking over from the Stop & Go was 0.6 s.

6.3.2 Mental workload

General

In this section, we gladly made use of the work of Hof (2005), which was conducted as part of a graduate thesis. For the analysis on heart rate, data from six participants were not considered, because of the bad quality of these ECG signals. For the analysis on the peripheral detection task (PDT), data from two participants were not considered. These participants indicated after the experimental runs to have difficulties with performing this extra task.

Several measures were used to examine the participants' mental workload during driving with the Congestion Assistant. Generally, the higher the average heart rate (HR) and the lower the heart rate variability (HRV) in the 0.10 Hz band, the more mental effort had to be spent. Also, the larger the reaction time on the PDT and the more missed signals, the more demanding was the primary task (i.e. driving). And the higher the score on the Rating Scale Mental Effort (RSME), the higher was the experienced workload.

First, it was examined whether the mental workload during the four experimental runs differed from the mental workload at rest. Therefore, repeated measures ANOVAs were performed on heart rate using Run (5 levels) as a within-subject factor. The results showed that Run had no effect on the HR [$F(4,120) = 1.74$, n.s.]. However, it did have an effect on the HRV [$F(4,120) = 8.99$, $p<0.001$]. The power value of the HRV at rest was higher than during any of the experimental runs. This means that driving during these runs resulted in a higher mental workload than sitting in the driving simulator doing nothing.

Heart rate

The results concerning the *HR* revealed an interaction effect between System and Section [$F(3,81) = 6.55$, $p<0.001$], see Figure 6.15. The figures concerning average heart rate display the HR scores, although the IBI scores were used in the HR analyses. The HR with the Congestion Assistant was lower than without the system, but only in the traffic jam (section

3). This means that the mental workload was lower in the traffic jam when one was driving with the Stop & Go of the Congestion Assistant.

The results concerning the *HRV* revealed that the heart rate variability did not seem to be affected by the functions of the Congestion Assistant or the visibility conditions.

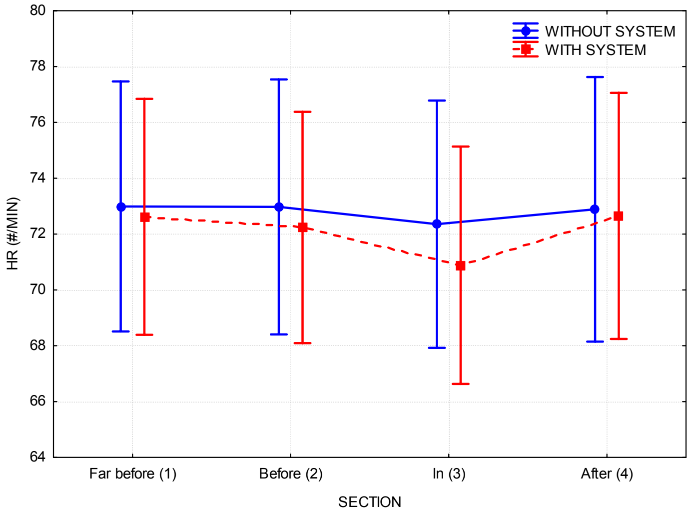


Figure 6.15: HR as a function of System and Section

Peripheral Detection Task

The results concerning the *reaction time to the PDT* revealed an interaction effect between System and Section [F(3,93) = 9.55, p<0.001], see Figure 6.16. The average reaction time with the Congestion Assistant was larger than without the system, but only when approaching the traffic jam (section 2). This indicates that the mental workload was higher in this section when one was driving with the Active pedal of the Congestion Assistant.

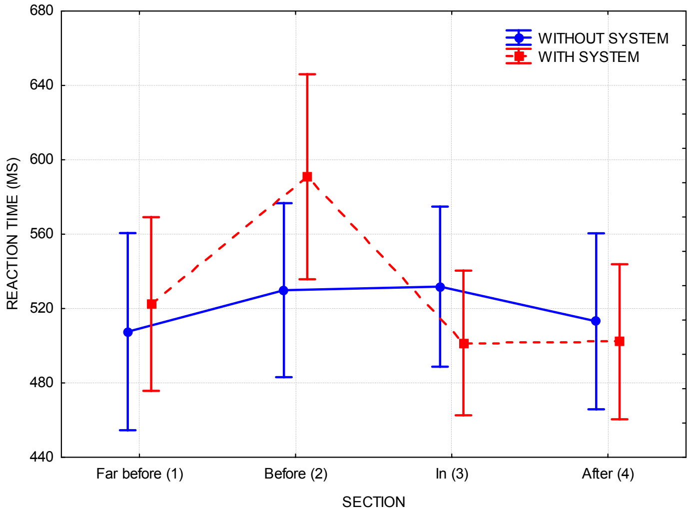


Figure 6.16: Reaction time to PDT signals as a function of System and Section

The Friedman results concerning the *percentage of missed PDT signals* revealed main effects of System [p<0.03] and Section [p<0.001], see Figure 6.17. When approaching the traffic jam (section 2), the percentage of missed PDT signals with the Congestion Assistant was larger than without this system [p<0.01]. This indicates that the mental workload was higher in this section when one was driving with the Active pedal of the Congestion Assistant.

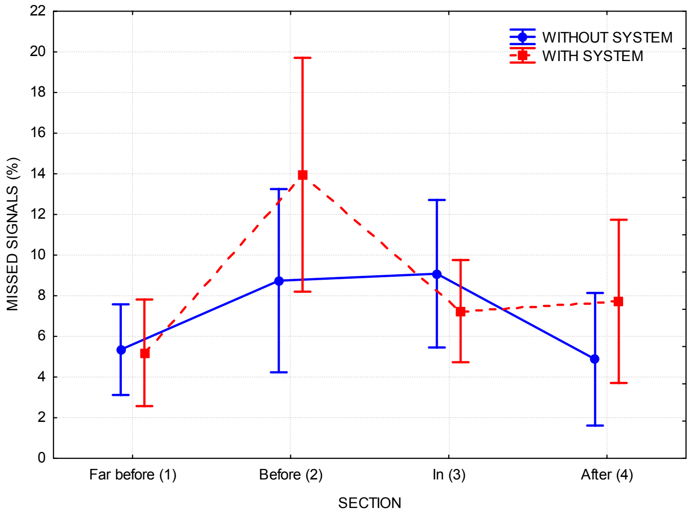


Figure 6.17: Percentage of missed PDT signals as a function of System and Section

Rating Scale Mental Effort

The results concerning the *RSME* revealed an interaction effect between Visibility and System [F(1,33) = 0.00, p<0.01], see Figure 6.18. More effort was put into driving in fog than driving during normal visibility, but only when one was driving without the Congestion Assistant. In fog, the experienced workload with the Congestion Assistant was lower than without the system.

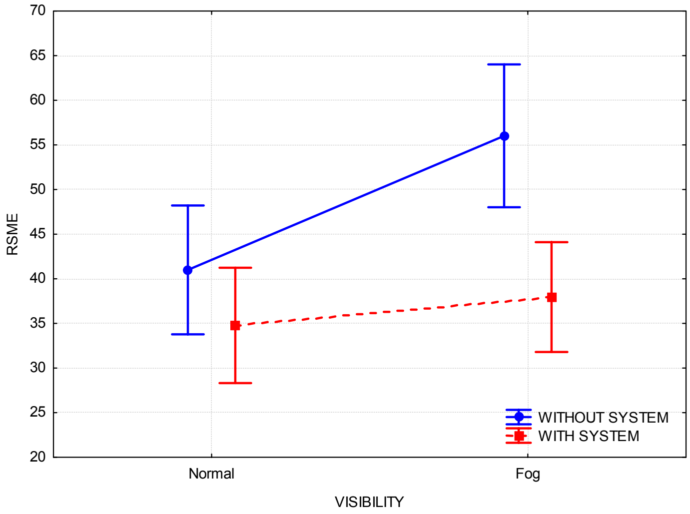


Figure 6.18: RSME as a function of Visibility and System

Summary

The impacts of the Congestion Assistant on mental workload were the following:

- The mental workload was higher when the participants approached the traffic jam with the Active pedal than without this function
- The Stop & Go led to a lower mental workload in the traffic jam compared to unsupported driving
- In fog, the experienced mental workload with the Congestion Assistant was lower than without this system

6.3.3 Acceptance

General

The 37 participants completed questionnaires with respect to the acceptance of the Congestion Assistant and the willingness to buy the system. However, three answers on the acceptance checklists were missing. These missing values were replaced with a zero (i.e. ‘neutral’). This way, the data sets of all participants could be used in the statistical analyses. At the end of the experiment, participants had the possibility to write down their comments on the study.

Usefulness and satisfaction

The acceptance scores on the nine separate items of the Van der Laan questionnaire were transformed into the underlying dimensions, usefulness and satisfaction, by computing the averages of the corresponding items. Table 6.7 shows the acceptance scores for the total Congestion Assistant and for the three functions separately, with u=usefulness and s=satisfaction. A distinction was made between before driving, after driving during normal visibility and after driving in fog.

Table 6.7: Acceptance scores on usefulness and satisfaction

	Before		**After normal**		**After fog**	
	u	*s*	*u*	*s*	*u*	*s*
Congestion Assistant	0.97	0.80	1.04	0.97	1.22	0.99
Warning & Information	1.24	0.97	1.36	1.06	1.49	1.10
Active pedal	0.67	-0.01	0.51	-0.17	0.59	-0.09
Stop & Go	0.56	0.37	0.97	0.93	1.02	0.94

It can be seen that the acceptance of the Congestion Assistant is fairly high: average scores around 1.0 on a scale from -2 to +2. However, the acceptance scores of the Congestion Assistant did not surpass the scores of its functions. In particular, the Warning & Information was highly valued, whereas the Active pedal received least acceptance [$F(2,70) = 25.79$, $p<0.001$]. Generally, the participants thought that the Congestion Assistant was more useful than satisfying [$F(1,35) = 10.39$, $p<0.01$]. This also applied to the Warning & Information and the Active pedal. However, Figure 6.19 shows that the Stop & Go was regarded as useful as satisfying [$F(2,70) = 19.48$, $p<0.001$].

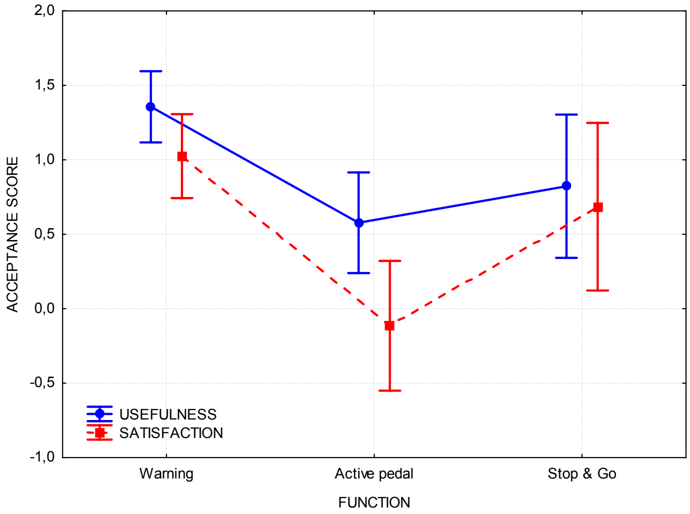


Figure 6.19: Acceptance score as a function of Dimension and Function

Visibility and experience

No significant differences between the two visibility conditions on the acceptance scores were found, although the results indicated that the Congestion Assistant was more accepted after driving in fog than before driving and after driving during normal visibility [F(2,70) = 2.56, p<0.08].

Furthermore, Figure 6.20 shows that the participants were less positive about the Stop & Go before driving with the Congestion Assistant than after driving with the system, regardless of the visibility conditions [F(4,140) = 7.15, p<0.001]. Thus, gaining experience led to a higher acceptance score of the Stop & Go, while it did not affect the acceptance scores of the Warning & Information and the Active pedal.

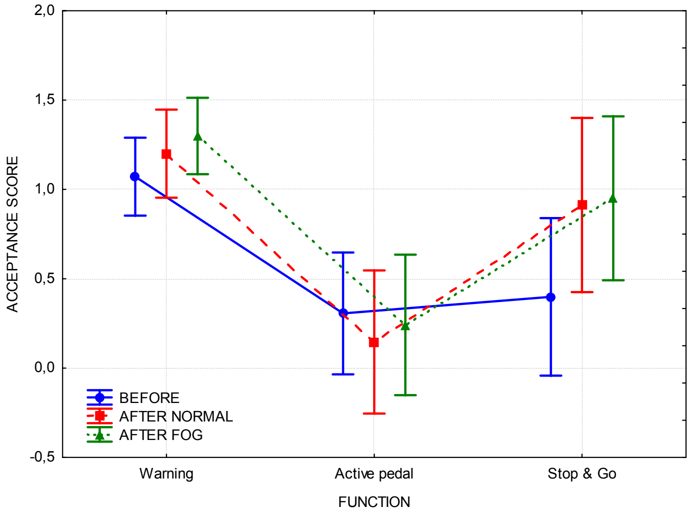


Figure 6.20: Acceptance score as a function of Experience and Function

Willingness to buy

The results of willingness to buy the Congestion Assistant concerned the scores on the Juster scale, see Figure 6.21. The mean score on this 11-point scale was 5.35. This value corresponded to the answers: ‘fairly good possibility’ and ‘good possibility’. The most frequently given answer showed that 27% of the participants thought it was ‘very probable’ to buy the Congestion Assistant that was priced €1500. In general, the participants revealed a fairly high willingness to buy the system.

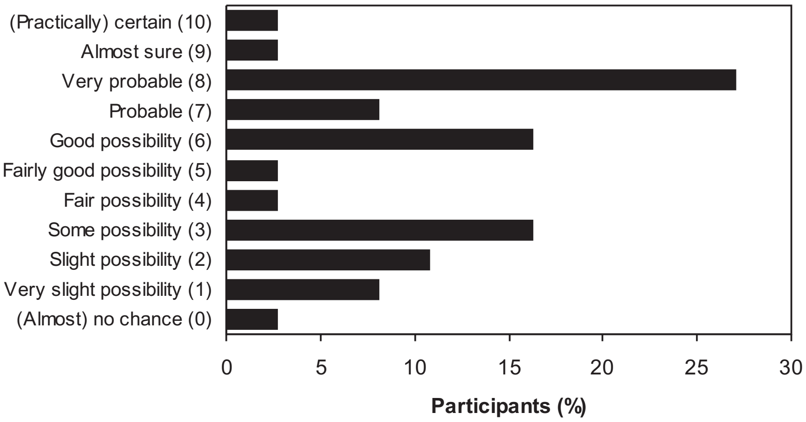


Figure 6.21: Willingness to buy the Congestion Assistant

Relations between needs, acceptance and willingness to buy

It is assumed that in-vehicle systems should fit the needs of potential users and be accepted by these users; otherwise they will not be willing to purchase these systems. Participants of the driving simulator experiment also completed the user needs survey. This enabled to explore the extent to which their needs for congestion assistance in general were related to their acceptance of the Congestion Assistant. This also enabled to study to what extent their acceptance of the Congestion Assistant was related to their intention to buy this system.

The results concerning the relations between *needs and acceptance* revealed an interaction effect between Dimension and Attitude [$F(1,35) = 6.44$, $p<0.05$], see Figure 6.22. It appeared that participants who held a positive attitude towards congestion assistance were more positive about the satisfaction of the Congestion Assistant. However, the two groups (i.e. participants with a positive or negative attitude towards congestion assistance) did not differ on their opinion about the usefulness of the Congestion Assistant.

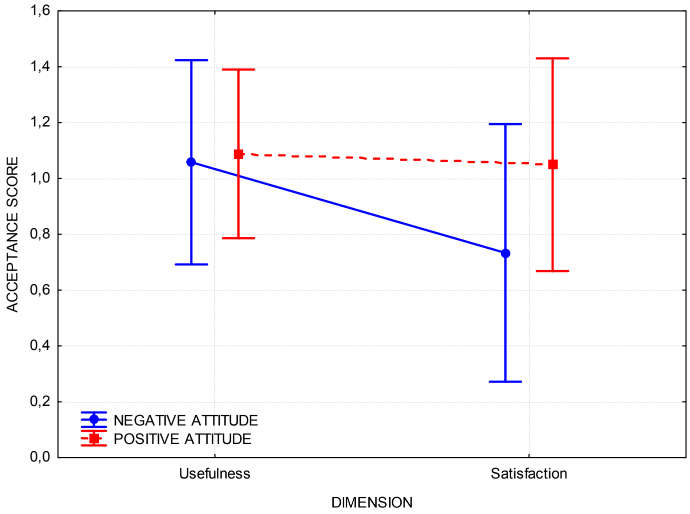


Figure 6.22: Acceptance score as a function of Attitude and Dimension

It was expected that the ‘positive’ and ‘negative’ participants would differ from each other on their acceptance of the three functions of the Congestion Assistant. However, the repeated measures ANOVAs did not reveal such differences. This might be due to a loss of discrimination with increasing degrees of freedom. Therefore, the acceptance scores of the two groups with respect to the three functions were also analysed using independent samples T tests. These results showed that Attitude affected the acceptance scores to some extent. Before gaining experience with the Congestion Assistant, the participants with a positive attitude towards congestion assistance rated the satisfaction of the Warning & Information and the Stop & Go higher than the participants with a negative attitude (1.15 vs. 0.72 and 0.73 vs. -0.15). Obviously, the indicated user needs corresponded to how satisfying one thinks these functions would be before gaining experience with them. Especially participants with a negative attitude positively changed their opinions about (functions of) the Congestion after gaining experience with the system.

The results concerning the relations between *needs and willingness to buy* showed that the mean score on the Juster scale of participants who held a positive attitude towards congestion assistance was 5.82 compared to 4.40 of participants with a negative attitude. Although the ‘positive’ participants indicated a higher willingness to buy the Congestion Assistant than the ‘negative’ participants, this difference in willingness to buy was not significant [t(35) = -1.55, n.s.]. This means that the initial attitude towards congestion assistance in general – based on the participants’ survey answers – had no influence on the willingness to buy the Congestion Assistant.

The results concerning the relations between *acceptance and willingness to buy* revealed significant correlations between the Van der Laan scores and the Juster score. Table 6.8 shows these correlations for the total Congestion Assistant and for the three functions separately, with u=usefulness and s=satisfaction. A distinction was made between before driving and after driving during normal visibility.

Table 6.8: Correlations between acceptance and willingness to buy

	Juster score
Acceptance score before	
Congestion Assistant – s	.445**
Stop & Go – s	.354*
Acceptance score after normal	
Congestion Assistant – u	.563**
Congestion Assistant – s	.515**
Warning & Information – u	.414*
Active pedal – u	.497**
Active pedal – s	.440**
Stop & Go – u	.441**
Stop & Go – s	.490**

* Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level

It can be seen that before driving with the Congestion Assistant, only the satisfaction scores of the total system and the Stop & Go showed positive correlations with the Juster score. However, after gaining experience with the system, the results showed more relations between the acceptance scores and the Juster score. The positive and significant correlations between the acceptance of the Congestion Assistant after driving during normal visibility and the willingness to buy the system implied that the higher one rated the acceptance of the system, the more one indicated to be willing to buy it. The dimensions of the scores (i.e. usefulness and satisfaction) did not affect these results. This was also true for the Active pedal and the Stop & Go. Thus, the higher one rated the Active pedal and the Stop & Go, the more one indicated to be willing to buy the Congestion Assistant. The influence of the acceptance scores of the Warning & Information was less clear. Only the usefulness of the Warning & Information seemed to affect the willingness to buy the system.

The above-mentioned results showed that the user needs for congestion assistance were linked to the acceptance of the Congestion Assistant. However, this relation only indicated how satisfying the participants thought this system would be before actually gaining experience with it. Thus, expressing needs for driver assistance can be considered a condition for actually accepting this in-vehicle technology, although gaining experience with a system can alter the acceptance of it. The needs were not related to the willingness to buy the system. However, the acceptance of the Congestion Assistant after gaining experience with it did contribute to the explanation of willingness to buy the system. Thus, evaluating a driver support system as acceptable can be considered a condition for actually purchasing it. Figure 6.23 presents these relations between needs, acceptance and willingness to buy.

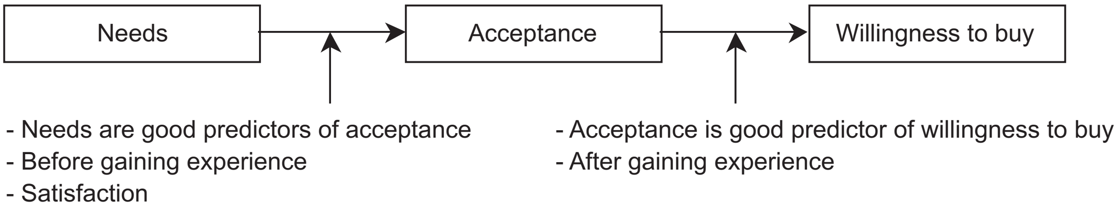


Figure 6.23: Relations between needs, acceptance and willingness to buy

6.4 Discussion

6.4.1 Overview of results

The impacts of the Congestion Assistant on the driver in two visibility conditions (i.e. normal view and fog) were studied by means of a driving simulator experiment. This section discusses the results on driving behaviour, mental workload and acceptance. The hypotheses mentioned in Section 6.1 serve as a guideline for presenting these results.

Driving behaviour

It was found that the mean speed with the Congestion Assistant was lower than without this system, but only during normal visibility. Furthermore, the maximum deceleration level with the Congestion Assistant was lower than without this system. In other words, the participants braked less hard when driving with the Congestion Assistant. Table 6.9 shows the effects of the Congestion Assistant and its functions on driving behaviour.

Table 6.9: Effects of the Congestion Assistant on driving behaviour

	Driving behaviour
Congestion Assistant	Lower mean speed (only during normal visibility) Lower maximum deceleration level
Warning & Information	No effects
Active pedal	Lower mean speed Larger standard deviation of speed Higher minimum Time-To-Collision (TTC)
Stop & Go	Smaller time headway Smaller standard deviation of time headway Lower minimum Time-To-Collision (TTC) Lower mean and maximum acceleration Lower mean deceleration level Less steering effort

It was expected that the participants were better prepared for the traffic conditions ahead by the *Warning* function. However, the results on driving behaviour did not show any impacts when approaching the traffic jam up to 1.5 km. This might be explained by the fact that the participants were still relatively far away from the jam (i.e. between 5 and 1.5 km). Remarks from some of the participants confirmed this. They thought that the first warning at 5 km before the traffic jam was ‘too early’. Although this function did not significantly affect driving behaviour, it was assumed that it increased the participants’ attention, which could lead to a decreased accident risk.

The *Active pedal* and the Warning function were both active when running into the traffic jam. However, it was assumed that particularly the Active pedal affected the driving behaviour, because this function was more compelling. It was expected that the participants would better anticipate the traffic jam. The results showed a lower mean speed, a larger time headway and a larger minimum TTC due to the Active pedal, indicating earlier speed adaptations and safer car-following behaviour when approaching the jam. Also a larger standard deviation of speed was found with the Active pedal. This was an inherent part of the working of this function as it gradually reduced speed toward the jam (e.g. from 120 to 50 km/h). On the contrary, without the Active pedal, the participants continued driving at a high speed until noticing the traffic jam, which led to smaller variations in their speed. The Active pedal did not result in a lower deceleration level. So the participants braked equally hard regardless of driving with or without the Active pedal.

In the traffic jam, both the *Stop & Go* and the Information function were working. Since the participants could not overrule the Stop & Go, the effects on driving behaviour were due to the Stop & Go. By automating the longitudinal driving task, it was expected that the Stop & Go would perform the car-following task more efficiently. The results showed that the Stop & Go led to a lower mean and maximum acceleration and to a lower mean deceleration level. So the Stop & Go accelerated and braked less hard than participants without the system did. The acceleration results could indicate a slower response of the Stop & Go to the other traffic. However, the time headway results seem to show the opposite. The Stop & Go operated at a time headway of 1.0 s. According to the results on mean time headway, the Stop & Go indeed followed a lead vehicle closer (i.e. at smaller time headways) than the participants 'normally' did. So the smaller accelerations and decelerations are better interpreted as 'smoother driving' with small headways. More time headways between 1 s and 2 s were observed with the Stop & Go; however, no differences were found with respect to the minimum time headway. The Stop & Go also led to a smaller minimum TTC. These findings do not necessarily indicate potentially dangerous following situations, since automating the car-following task during congestion can eliminate possible human errors during this driving task. Furthermore, the standard deviation of time headway with the Congestion Assistant was smaller than without the system. These smaller differences in time headway due to the Stop & Go possibly indicate a better following behaviour because of a more homogeneous headway distribution. Driving with the Stop & Go led to a decreased steering effort. Because the Stop & Go took over the longitudinal driving task, the participants presumably had to invest less effort in the steering task.

The (de)activation of the Stop & Go was introduced by a spoken message. Most participants used the time between this message and the actual (de)activation to prepare for the Stop & Go actually turning on or off. For example, more than half of the participants already got their foot on the gas pedal when the Stop & Go switched off. The mean reaction time of taking over from the Stop & Go was about 0.6 s. This is much faster than the 2.0 s found by Reichardt (1998). However, in his study the drivers were working in the car (e.g. office on wheels) during automatic car driving, while in our study this was not the case. Somewhat related to taking over from the Stop & Go in our study, is reclaiming control of a driver support system in critical situations. Drivers supervising automated vehicles tended to not reclaim control in time during critical situations, such as braking lead cars or crossing traffic (Desmond et al., 1998; Stanton et al., 2001; De Waard et al., 2004). However, a large difference is that our participants got a warning about when to take over from the system, instead of suddenly having to take over control.

Because of the *Information* given by the Congestion Assistant, one knows when the traffic jam comes to an end. Therefore, it was expected that after the traffic jam the maximum acceleration with the system would be higher than without. The data did not clearly support this expectation. However, the participants followed their predecessor closer after the jam when they had driven with the Congestion Assistant. Probably, they got used to driving at small time headways because the Stop & Go also displayed this behaviour in the traffic jam.

Mental workload

It was expected that drivers would have to invest less effort in driving with the Congestion Assistant than without this system. This expectation was confirmed by the RSME data. Participants experienced a lower mental workload with the Congestion Assistant, but only when driving in fog. Table 6.10 shows the effects of the Congestion Assistant and its functions on mental workload. It can be seen that the results obtained by the Peripheral Detection Task (PDT) did not correspond to the results from the heart rate data. Possibly, this has to do with differences between the measures with respect to sensitivity. For example, the PDT might be more sensitive towards visual workload. It was concluded that the combination of workload measures enabled us to form a more complete picture of the driver's mental workload caused by the Congestion Assistant.

Table 6.10: Effects of the Congestion Assistant on mental workload

	Mental workload
Congestion Assistant	Lower workload (only in fog) (based on RSME data)
Warning & Information	No effects
Active pedal	Higher workload (based on PDT data)
Stop & Go	Lower workload (based on heart rate data)

No impacts of the *Warning* function on mental workload were found. The PDT data showed that the workload with the *Active pedal* was higher than without this function. This could mean that the Active pedal led to a higher degree of drivers' attention towards the upcoming traffic jam, which resulted in a decreased performance on the secondary task. However, it might also be possible that the Active pedal itself led to a higher workload, for example by 'suddenly' producing a counterforce of the gas pedal. This latter result shows similarities to the results by Hogema & Rook (2004). They found that the subjective workload of driving with a high-force ISA was higher than driving with a low-force ISA or with no ISA.

Confirming our expectations, the *Stop & Go* resulted in a lower mental workload based on the heart rate data. Some participants expressed concerns about a possibly weakened attention due to the Stop & Go. One participant even fell asleep when the Stop & Go was active. In this case, it might have been better to keep the driver 'out of the loop' while the Stop & Go performed the lateral driving task as well. Although this incident could be attributed to other factors than driving with the Congestion Assistant, it is important to keep in mind that automation of (parts of) the driving task might decrease the driver's alertness and be sleep-inducing. In this experiment, the driver could not overrule the Stop & Go. Including intervention possibilities for the driver could be beneficial for the driver's alertness. To be acceptable, mental workload should not be excessively high. Conceptually, it should be below a critical redline level (Colle & Reid, 2005). This driving simulator experiment showed that a redline for excessively low mental workload should also be considered. However, the determination of a general valid level appears to be difficult owing to individual differences in workload and the relative nature of mental workload (De Waard, 1996).

Acceptance

The driving simulator experiment showed that the total *acceptance* of the Congestion Assistant was fairly high: average scores around 1.0 on a scale from -2 to +2. However, not all functions were equally appreciated. Although systems that restrict the driver's behaviour generally are less accepted than non-restrictive, informative systems (Van der Laan et al., 1997), this was not confirmed by our study. It appeared that the (informing) Warning & Information as well as the (controlling) Stop & Go were accepted most. Probably, drivers appreciated to be released by the Stop & Go from the uncomfortable task of congestion driving. The Active pedal was least accepted, especially the satisfaction with this function. Furthermore, the results from the user needs survey indicated great needs for driver assistance in reduced visibility situations. However, the expectation that the Congestion Assistant would be accepted more in fog than during normal visibility was not clearly supported by the results. In most cases drivers are more positive about a driver support system after having gained experience with it (TRG, 2004). Gaining experience, however, only led to a higher acceptance score of the Stop & Go. Table 6.11 shows the effects of the Congestion Assistant and its functions on acceptance.

Table 6.11: Effects of the Congestion Assistant on acceptance

	Acceptance
Congestion Assistant	Average acceptance score: 1.00 (on a scale from -2 to +2) More useful than satisfying
Warning & Information	Average acceptance score: 1.20 More useful than satisfying
Active pedal	Average acceptance score: 0.25 More useful than satisfying
Stop & Go	Average acceptance score: 0.80 More accepted after gaining experience
Visibility	No effects
Attitude	Positively correlated with satisfaction scores
Willingness to buy	Mean: ‘good possibility’ and modus: ‘very probable’ Positively correlated with acceptance scores

Since participants of the experiment were selected from respondents to the user needs survey, this enabled the exploration of relations between *needs and acceptance*. As hypothesized, the results from the experiment appeared to be consistent with the results from the survey. Participants who held a positive attitude towards congestion assistance – based on their survey answers – were more positive about the Congestion Assistant than participants with a negative attitude. This finding particularly applied to the satisfaction scores of the Warning & Information and the Stop & Go before gaining experience with the Congestion Assistant. Thus, the indicated user needs corresponded to how satisfying one thought these functions would be before gaining experience with them. However, driving with a system can alter the acceptance of the system, similar to the (higher) acceptance of the Stop & Go after gaining experience with it. Following the user needs survey, the Congestion Assistant especially fitted the perceived needs for warnings for downstream traffic conditions (i.e. Warning & Information) and support with congestion driving on motorways (i.e. Stop & Go). Since the survey did not include a function like the Active pedal, it is therefore not surprising that the ‘positive’ and ‘negative’ participants did not differ between their acceptance of this function. It was concluded that the user needs survey revealed to be a valid method for the indication of user needs for congestion assistance. Expressing needs for driver assistance can be considered a condition for actually accepting this in-vehicle technology, although gaining experience with a system can alter the acceptance of it.

The Juster scale was used to measure the *willingness to buy* the Congestion Assistant. The mean and modus scores showed a fairly high probability of buying the Congestion Assistant at the price of €1500. The indicated user needs for congestion assistance had no influence on the willingness to buy the system. But the acceptance of the Congestion Assistant after driving with it did contribute to the explanation of willingness to buy the system. The higher one rated the acceptance of the system, the more one indicated to be willing to buy the system. Thus, evaluating a driver support system as acceptable can be considered a condition for actually buying it. However, since the Congestion Assistant is not available on the market, more research is needed to investigate the factors influencing the purchase of such in-vehicle systems in reality.

6.4.2 Implications of appearance of traffic jam

The Congestion Assistant was tested in specific congested traffic situations. Each participant completed four experimental runs that included a traffic jam starting and ending around fixed points. However, the jam did not always appear correctly between these fixed points because of programming errors. This could mean, for example, that the Active pedal was already giving a counterforce while the traffic ahead was not congested yet. Some extra statistical analyses were therefore performed with data from participants with a 'good' (i.e. intended) start and end of the traffic jam. Generally, these extra analyses confirmed the overall results with respect to driving behaviour. This means that the timing of the traffic jam hardly influenced the impacts of the Congestion Assistant on driving behaviour. The extra analyses showed:

- No higher steering effort with the Active pedal when approaching the jam
- Less hard braking behaviour with the Active pedal when approaching the jam (i.e. lower mean and maximum deceleration levels)
- No higher mean and maximum acceleration with the Congestion Assistant when leaving the jam

Thus, the extent to which the Congestion Assistant affected the steering effort and the deceleration behaviour before the traffic jam, and the acceleration behaviour after the jam was influenced by the (unintended) appearance of the traffic jam.

The use of the Congestion Assistant with respect to the Active pedal and the Stop & Go seemed to be affected by the timing of the traffic jam as well. During normal visibility, participants with a 'good' start of the traffic jam felt the counterforce at a smaller distance from the tail of the traffic jam. Presumably, these participants already slowed down earlier themselves because the traffic was becoming congested (as intended), so that the warning of the Active pedal could be delayed. Moreover, the Active pedal was being less overruled by in these cases. During the Stop & Go mode, the participants sometimes used the gas pedal. This could also have to do with the delayed start or too early end of the traffic jam. For example, when no lead car was present, the Stop & Go would accelerate towards a speed of 70 km/h. When participants wanted to drive faster, this was not possible although they could have tried it by pressing the gas pedal.

The possible influence of the appearance of the traffic jam on the acceptance scores was studied as well. The way in which the participants ran into the traffic jam did not affect the acceptance scores of the Congestion Assistant and its functions after driving during normal visibility. However, in fog, participants with a 'bad' start of the traffic jam were less positive about the Active pedal and the Stop & Go than participants for whom the traffic jam started as intended. Thus, the programming errors also contributed to the acceptance scores of these functions. This should be kept in mind, particularly regarding the acceptance scores of the Active pedal, which were not very positive (usefulness) and even negative (satisfaction).

Considering the above, it can be concluded that further research is needed to create more realistic and 'reliable' congestion in a driving simulator environment.

6.4.3 Conducting the experiment

The participants drove with the Congestion Assistant in TNO's advanced driving simulator. Validation studies showed a good agreement between driving behaviour in real traffic and in this driving simulator (Kaptein et al., 1996; Hoedemaeker et al., 2002). To enhance its validity, the driving simulator is placed on a moving base to provide the driver with realistic inertial forces during braking, cornering and driving on rough roads and humps. Johansson et al. (2005) stated that car-following and steering-related measures are more powerful in a full-scale driving simulator environment compared to a laboratory setting. Furthermore, De Vos et al. (1998) found that participants braked more moderately with motion cuing, although no effects of motion cuing on the TTC, the stopping distance and the percentage of collisions were observed. Unfortunately, the moving base of our driving simulator broke down halfway the experiment. However, the between-subject factor Motion showed no effects on the results, except for an effect on the standard deviation of speed, which could be explained by the 'bad' timing of the traffic jam. It was therefore concluded that the breakdown of the moving base appeared to have no meaningful influence on the results of this experiment.

It was assumed that the participants got a good idea of the working of the Congestion Assistant by driving in the driving simulator. However, the results reflected their first impressions of the system, as opposed to the reactions they might show after a longer exposure to it. Moreover, in this experiment the Congestion Assistant worked as intended. In the real world, however, it might be possible that the system displays false Warnings or shows unexpected behaviour of the Active pedal or Stop & Go. False alarm rates should be minimized, because the more reliable the alarm signals, the better the driving performance (Bliss & Acton, 2003). According to Lee & See (2004), automation should be made 'trustable' by conveying the possibilities and limitations of a system to potential users. A diversity of measures was used to study the impacts of the Congestion Assistant on driving behaviour, mental workload and acceptance. These measures gave insight into the participants' behavioural reactions when driving with the system. However, more detailed information could be gained with other measures. For example, speed profiles and the standard deviation of deceleration can provide more knowledge of the effects of the Active pedal on anticipating the jam.

The Van der Laan questionnaire was used to measure the perceived usefulness and satisfaction of the Congestion Assistant. This questionnaire has been applied in earlier studies to assess the acceptance of new in-vehicle technology (Van der Laan et al., 1997). However, it does not include other aspects of acceptance, such as affordability and social acceptability, although it is thought that these aspects as well will determine the eventual willingness of drivers to use the technology (Regan et al., 2002). This is in line with the Theory of Planned Behaviour that proposes that the intention to engage in a particular behaviour, such as using the Congestion Assistant, can be predicted from the attitude towards that behaviour, the subjective norm with respect to that behaviour and the perceived behavioural control over that behaviour (Ajzen, 1991). In addition, the Juster scale was used to measure the willingness to buy the Congestion Assistant. This scale can be considered an accurate measure of future purchase behaviour, especially with respect to products and services already on the market (Brennan & Esslemont, 1994). It revealed to predict the purchase of new products less well (McDonald & Alpert, 2001). This was attributed to the consumers' inability to foresee intervening situational factors, rather than inaccuracies in the scale itself. Unfortunately, we could not investigate the actual purchase and usage behaviour with respect to the Congestion Assistant, since this system is not available on the market. Further research should therefore examine factors influencing the actual purchase and usage of in-vehicle systems, such as the Congestion Assistant, in reality.

The participants of the driving simulator experiment were selected from the respondents to the user needs survey. The composition of the sample focused on the initial attitude towards congestion assistance based on the survey answers with little emphasis on other personal characteristics such as gender. The sample of participants did not resemble the Dutch population of car drivers. Therefore, the results of this experiment are particularly valid for this subset. None of the participants had experience with driving in a driving simulator. The validity of a driving simulator appears to be very good for experienced car drivers and weaker for persons that have difficulties with driving (Hakamies-Blomqvist et al., 2001). The participants of our experiment can be considered experienced car drivers (e.g. mileage >10.000 km/year). They did not seem to have any difficulties with driving in the simulator. It was therefore concluded that the inexperience with the driving simulator did not have an influence on the results.

6.5 Conclusions

This chapter presented the results from a driving simulator experiment with 37 participants gaining experience with the so-called Congestion Assistant. This in-vehicle system supported the driver during congested traffic conditions on motorways. The Warning & Information function provided warnings for traffic jams ahead and information about the length of these jams. The Active pedal slowed down the driver when approaching the jam at too high speed, while the Stop & Go took over the longitudinal driving task in the jam. Participants of the driving simulator experiment were selected from respondents to the user needs survey. The results from the experiment appeared to be consistent with the results from the survey. That is, the acceptance of the Congestion Assistant was found to be related to the indicated needs for congestion assistance. Generally, the participants stated that they appreciated the Congestion Assistant and were willing to buy the system. They thought it could help increase traffic safety and traffic efficiency and decrease emissions. The results on driving behaviour also pointed in that direction. For example, speed reductions caused by the Active pedal could enhance traffic safety. Furthermore, smaller time headways by the Stop & Go might enhance traffic efficiency, while smoother accelerations and decelerations could indicate fewer emissions.

The participants experienced a lower mental workload with the Congestion Assistant, but only when driving in fog. The mental workload was higher when one approached the traffic jam with the Active pedal, but the Stop & Go resulted in a lower mental workload. The Congestion Assistant was valued highly, although not all functions were equally rated. Participants particularly favoured the Warning & Information and the Stop & Go. The acceptance of the Stop & Go significantly increased after having gained experience with the system. The Active pedal negatively influenced the acceptance of the Congestion Assistant. To increase the acceptance of the total system, the following suggestions for enhancement were made. Congestion warnings should not be given too early, for example not at 5 km from the traffic jam. The Active pedal should operate more as a final warning, for example by only providing haptic feedback when the driver is very near to the tail of the traffic jam (e.g. 500 m). The Stop & Go should be overrulable by the driver, for example by using the gas or brake pedal.

In summary, the Congestion Assistant showed indications of an improved traffic safety when approaching a traffic jam due to the Active pedal, although the participants did not express great appreciation of this function. Moreover, positive effects on traffic safety and traffic efficiency in a traffic jam can be expected by the Congestion Assistant due to the Stop & Go, a function which was highly appreciated by the participants. The next step in this project was to investigate to what extent these effects prevail when focusing on a whole traffic flow instead of only one driver. The results from the driving simulator experiment served as input for a microscopic traffic simulation study (see Chapter 8). The impacts of varying penetration rates and parameters of the Congestion Assistant on traffic efficiency and traffic safety were topics of interest. But first, the next chapter will discuss the methodology of traffic simulation studies and the findings of earlier studies into the traffic flow effects of driver support systems.

Chapter 7

Literature on effects of driver support systems on traffic efficiency and traffic safety

Individual driving behaviour determines to a large extent how efficient and safe the traffic flow behaves. So it is important to understand the significance of a change in individual driving behaviour (e.g. due to driver support systems) in relation to the performance of a whole traffic flow. This chapter describes the research methodologies for exploring the impacts of in-vehicle technology on the traffic flow. In addition, it presents the results of earlier research into the impacts of driver support systems related to congested traffic situations on traffic efficiency and traffic safety. The chapter concludes with implications for this research. The findings of this chapter were used for the design of the traffic simulation study with the Congestion Assistant discussed in Chapter 8.

7.1 Introduction

High expectations rest on driver support systems in terms of a more efficient, safer and cleaner transport system. It is therefore important to study the actual contribution of these systems to the traffic flow by examining the interaction between driver and system as well as the interaction between vehicles on the road. Traffic flow effects of in-vehicle technology might be related to:

- Traffic efficiency: What are the improvements or deteriorations in traffic throughput resulting from vehicles equipped with the system? To what extent will the traffic flow be more efficient and homogeneous?
- Traffic safety: What are the improvements or deteriorations in traffic safety resulting from vehicles equipped with the system? To what extent will the traffic performance be safer?
- Emissions: What are the effects of the system on the emissions of noise and pollutants?

As we are particularly interested in the effects of driver support systems on congested traffic flows, the next section gives more information about congestion and indicators for measuring traffic performance. Several methodologies can be used to assess traffic flow effects of new in-vehicle technology. Ideally, the assessment of a system is based on measurements under a full-scale, real-life application. This is however not always practical, possible or safe. Therefore, traffic simulation models are often used to study the influence of vehicles equipped with the system on the total traffic flow. This research methodology is further described in the subsequent section. After that, the results of earlier research into traffic flow effects of driver support systems similar to the Congestion Assistant are discussed. The chapter concludes with implications for this research.

7.2 Congestion

7.2.1 Traffic breakdown

In this study, traffic breakdown is characterized as a motorway operation with a rapid drop in the speed level and a simultaneous increase in the traffic density, causing a change from smoothly flowing traffic to queuing traffic. Traffic breakdown becomes highly probable when traffic demand approaches or exceeds the available capacity of the motorway. The capacity of a motorway refers to the maximum amount of traffic capable of being handled by a given motorway section. The probability of traffic breakdown is related to: (1) the presence of bottlenecks, (2) the stability of the traffic flow, or a combination of both.

(1) Most traffic jams are associated with the presence of a bottleneck (Daganzo et al., 1999). A bottleneck can be defined as a location where either (a) traffic enters the motorway so that the sum of all traffic exceeds the capacity or (b) the capacity drops to a lower value than the actual flow it is carrying. The former happens at on-ramps or weaving sections, while the latter is related to, for example, accidents, work zones, tunnels or lane drops.

(2) Traffic flow (in)stability concerns the ability of the traffic flow to handle disruptions and prevent traffic breakdown. According to the traffic demand, three states of traffic flow can exist: (a) stable, (b) metastable and (c) unstable (Kerner, 1999). At small densities, the traffic flow is stable, which means that any disturbance will disappear when propagating through the flow. Above a certain critical density, the traffic flow is unstable, so that any disturbance will

trigger the formation of a traffic jam. Between the stable and the unstable region, a density interval exists where the traffic flow is metastable. In this region, small disturbances will fade away, while large disturbances exceeding a certain minimal amplitude will give rise to a traffic jam. Important factors that influence traffic flow (in)stability are the reaction time of drivers, the dynamic relaxation time and the anticipation behaviour of drivers. The reaction time of drivers is the time delay between their perception of the traffic state and their response to it (e.g. decelerating). The dynamic relaxation time is the time delay that the vehicle needs to respond to the driver's action (e.g. counteracting the speed difference), which depends on the deceleration level. The anticipation behaviour of drivers concerns the response of drivers to one or more vehicles ahead, based on (expected) actions of these vehicles.

The Congestion Assistant is expected to affect the instability of the traffic flow. The system could influence driving behaviour by decreasing the reaction time and increasing the anticipation behaviour of drivers, so that unstable traffic flows can be prevented or diminished. This, in turn, will lead to less (severe) traffic jams.

7.2.2 Macroscopic description of congestion

Free flow and congested flow are two familiar traffic flow regimes on motorways. In free flow the mutual influence of drivers is negligible, while in congested flow all drivers adapt their driving to other vehicles. Although traffic consists of individual vehicles, traffic flows characteristics can be described by the following key macroscopic variables (May, 1990):

- The flow q is defined by the number of vehicles at location x per unit of time Δt
- The density k is defined by the number of vehicles per unit of distance Δx at time t
- The speed u is usually calculated over time and represents the average speed of vehicles at location x per unit of time Δt

In a steady-state condition, flow, density and speed are related to each other as follows:

$$q = k \cdot u \tag{7.1}$$

The so-called fundamental diagram illustrates the relations between the three variables. Generally, such diagrams are based on measurements obtained from loop detectors (i.e. observations at a fixed location). Figure 7.1 shows an example of an empirical fundamental diagram based on measured loop data on the Dutch A12 motorway. The speed and flow data were collected about 700 m upstream of a lane drop from 4 to 3 lanes. The density data were obtained by using Equation 7.1. This fundamental diagram has some characteristics that have also been observed in other studies and can be regarded as generally accepted:

- The speed is more or less constant for low density and equal to the free speed u_0 (here about 110 km/h) and decreases when the density increases.
- Under some critical density k_c (here about 75 veh/km), strongly correlated flows and densities can be seen, referred to as the free flow branch. Above the critical density, a widely scattered point cloud can be observed, called the congestion branch.
- The maximum value of the flow is referred to as capacity or critical flow q_c (here about 7000 veh/h).
- At the critical density and the corresponding critical speed u_c (here about 70 km/h) the state of the traffic flow changes from stable to unstable. This transition can be seen from the speeds that in this example suddenly drop from values of 100 km/h and higher to values of 60 km/h and lower.
- The density associated with a stationary queue ($q = 0$ and $u = 0$) is called jam density k_j.

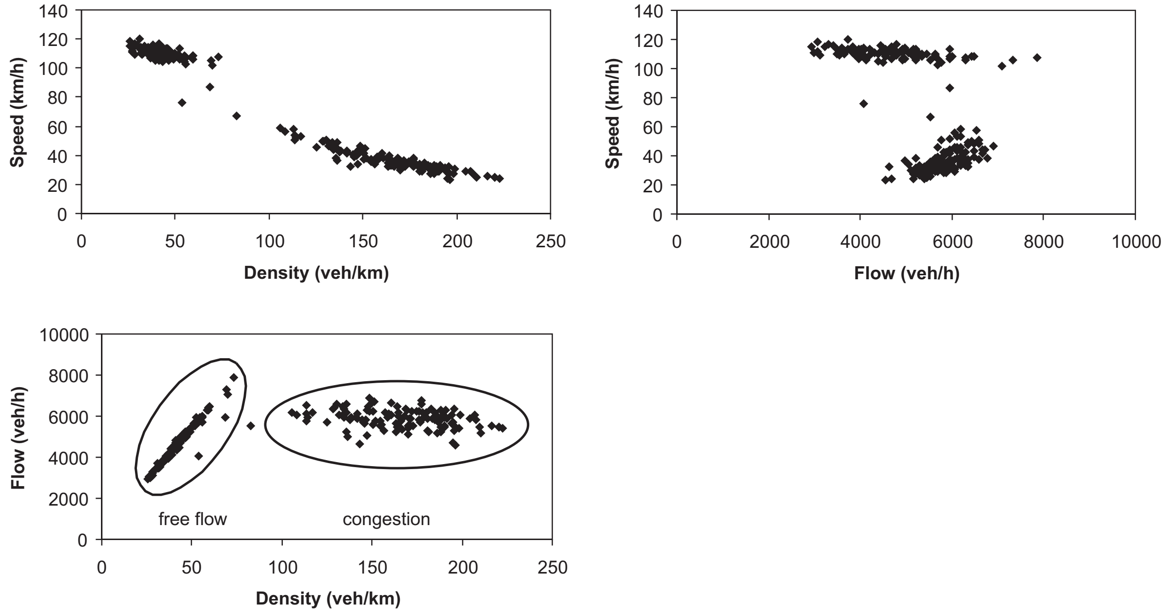


Figure 7.1: Empirical fundamental diagram based on data from Dutch A12 motorway upstream of lane drop from 4 to 3 lanes

The fundamental diagram reflects a local relationship between the variables, describing a traffic flow rather than predicting it. For example, the diagram only suggests correlations between decreasing speed and increasing density without indicating the causality. It neither reveals how the transition from free flow to congested flow occurs. The appearance of the fundamental diagram will vary depending on, among other things, the measurement location, the composition of traffic and the weather conditions. Nonetheless, the density reveals to be an important indicator of the traffic state.

7.2.3 Driving behaviour in congested situations

Traffic jams grow at the tail by the traffic feeding it and dissolve at the head by the traffic leaving it. Generally, drivers reveal to show specific car-following behaviour when they are approaching, driving in and leaving a jam.

Approaching a jam: queue tail

The process at the queue tail indicates whether the traffic jam will grow or not. This largely depends on the deceleration behaviour of drivers. Drivers approaching a traffic jam have to adapt their (high) speed to the (low) speed of the queue. This will not occur immediately because of the reaction time of drivers and the dynamic relaxation time. The resulting retarded deceleration can cause compression to higher density than that of the original queue, so that the flow becomes potentially unstable. However, drivers approaching a traffic jam have the ability to anticipate and thus start the deceleration before actually reaching the queue tail. Generally, the retarded deceleration and the ability to anticipate counteract each other: slower responses can be compensated by further anticipation. If anticipation were at least large enough to compensate a delayed response, this would lead to a stable propagation of jams. When anticipation cannot compensate a delayed response, jams will propagate and grow in amplitude.

Driving in a jam

Dijker et al. (1998) found that, at the same speeds, car drivers follow with larger distance headways in congested flow than in free flow. Probably, in congestion drivers experience no gains from high efforts in car-following behaviour anymore, thus the motivation to follow closely or take over slower cars is lower. Minderhoud & Zuurbier (2004) observed similar behaviour: on average, drivers reveal to keep much larger distance headways during stop-and-go conditions (speeds up to 60 km/h) compared to free flow (speeds above 80 km/h) and homogeneous congested conditions (speeds between 10 and 90 km/h). They concluded that drivers in stop-and-go conditions possibly want to avoid frequent accelerations and decelerations. This finding was confirmed by Hoogendoorn & Ossen (2005), who found that the reaction time of drivers during stop-and-go conditions was significantly higher than during heavy congestion. Also Piao & McDonald (2003) noticed that the time headways varied substantially at low speeds, but were relatively stable at high speeds. Because of unstable traffic conditions at low speeds, drivers were expected to adopt relatively large time headways to avoid rear-end collisions or putting pressure on the predecessor.

Leaving a jam: queue head

The process at the queue head determines how efficiently traffic can leave the congested regime and thus the jam will dissolve. Drivers respond with a certain delay to actions of their predecessor, generally leading to smaller gaps during decelerating and larger gaps during accelerating. As a result of this, the capacity of accelerating traffic (e.g. in the queue head) is lower than that of decelerating traffic which affects the recovery from congestion back to free flowing traffic.

The Congestion Assistant is expected to influence driving behaviour in the above-mentioned situations. The Active pedal of the system could smooth the traffic flow when approaching a jam by inducing better anticipation behaviour of drivers. The Stop & Go could follow other vehicles more efficiently when driving in and leaving a jam by maintaining smaller headways and eliminating the reaction time of drivers.

7.2.4 Indicators of traffic performance

Driver support systems may result in changes in driving behaviour, which in turn will influence the interactions with other vehicles and thus affect the performance of a traffic flow. Measures of traffic efficiency and measures of traffic safety are used to assess the impacts of such systems on the traffic performance. The most commonly used measures are presented in Table 7.1 and clarified below. Since we used a traffic simulation model to study the effects of the Congestion Assistant, the focus lies on measures that generally can be determined by such models.

Measures of traffic efficiency

As explained in the previous section, important information can be gained from the fundamental diagram, relating the key macroscopic variables flow, speed and density to each other. Particularly higher flows and higher speeds are indications for an improved traffic performance. Capacity gains can be derived from the so-called queue discharge flow, which is the maximum flow rate observed downstream of a bottleneck as long as the upstream congestion exists (Minderhoud, 1999). The queue discharge flow can be found in the speed-flow plot of the downstream location, but it can also be calculated, for example by averaging the three highest 5-minute traffic flows measured at the downstream location. Travel time – being strongly related to speed – is an important measure for the user-oriented quality of travelling (Kesting et al., 2007). The instantaneous travel time reflects mainly the perspective of the drivers, whereas the cumulative travel time is a performance measure that can be associated with the costs of traffic jams.

The traffic flow is less likely to break down if it is stable and homogeneous. This can be noticed from the speed variation: high standard deviations of speed suggest big fluctuations in the traffic flow. Also the distribution of vehicles over the lanes and the number of shock waves (i.e. discontinuities that propagate through the traffic flow) are indicators for the homogeneity of a traffic flow. An unbalanced distribution of vehicles over the lanes and a higher number of shock waves can explain reduced traffic performance. The number of shockwaves should ideally be interpreted in combination with the number of vehicles involved per shock wave to determine the severity of a shock wave (Hogema et al., 2002). Furthermore, the acceleration distribution can indicate how ‘smooth’ a traffic flow behaves. Especially hard braking (e.g. decelerations smaller than -3.5 m/s^2) indicates disturbances in the traffic flow. However, it should be noted that sometimes hard braking is necessary to avoid rear-end collisions that could obstruct the traffic flow much more.

Table 7.1: Measures of traffic efficiency and measures of traffic safety

	Traffic efficiency	**Traffic safety**
Flow-speed-density relations	x	
Queue discharge flow	x	
Travel time (instantaneous, cumulative)	x	
Speed variation	x	x
Distribution of vehicles over lanes	x	x
Shockwave information (number of waves, vehicles per wave)	x	x
Acceleration distribution	x	x
Time headway distribution		x
Time-To-Collision (TTC) distribution		x

Measures of traffic safety

One of the most revealing measures of traffic safety is the number of accidents or conflicts. However, traffic simulation models are generally not able to simulate accidents or conflicts and therefore do not provide such measures. Nonetheless, a variety of other, indirect safety measures can be determined, such as the time headway distribution and the Time-To-Collision (TTC) distribution. These measures can give insight into relative changes of traffic flow safety when comparing different scenarios with each other (e.g. supported versus non-supported driving). Time headways smaller than 1 s and TTCs smaller than 4 s generally refer to a higher accident risk (see also Section 5.2.2). Minderhoud (1999) proposed a set of safety indicators based on the TTC, among which the Time Exposed Time-to-collision (TET). The TET indicator expresses the drivers’ exposure to dangerous approaches to a predecessor based on a TTC threshold of 3 s.

The traffic flow is assumed to be safer if it is stable and homogeneous. Therefore, the same measures as mentioned above are applicable to indicate impacts on traffic safety: the speed variation, the distribution of vehicles over the lanes, shock wave information and the acceleration distribution.

7.3 Traffic simulation models

7.3.1 Microscopic modelling approach

Traffic flow modelling is done with the aim to describe traffic flows as realistic as possible, for example to examine the traffic flow effects of driver support systems. In this research, the impacts of the Congestion Assistant on motorway traffic were studied. This in-vehicle system showed to affect the driver and his driving behaviour (see Chapter 6). The modelling approach to be used has to meet some basic requirements. It should be able to:

- Simulate the traffic flow by distinguishing individual driver-vehicle combinations that represent the interactions between vehicles and between driver and vehicle.
- Simulate changes in driving behaviour – induced by driver support systems – so that the behaviour of vehicles equipped with or without these systems can be described.
- Simulate motorway environments including bottlenecks, such as on-ramps and lane drops that can cause congestion.
- Realistically represent traffic flow dynamics, particularly with respect to the congested regime and the transitions between free flow and congestion.

A microscopic modelling approach essentially meets these requirements. It describes the traffic flow by modelling the space-time behaviour of individual vehicles as well as their interactions at a high level of detail. It can also model the interaction between drivers and in-vehicle technology. These features make a microscopic modelling approach suitable for studying the traffic flow effects of driver support systems, such as the Congestion Assistant. The next section focuses on driving behaviour models that form an important part of microscopic traffic flow models.

7.3.2 Driving behaviour models

Driving behaviour models simulate the way a driver controls his vehicle. Generally, a distinction is made between the longitudinal driving task and the lateral driving task. The most relevant models for these tasks are described below, followed by a discussion of the validity of such models.

Longitudinal models

As opposed to free flow conditions, the motions of vehicles in congested flow conditions are hindered by the presence of other traffic. The term car-following model is used for the general class of models describing the longitudinal control task of a driver in relation to the driver(s) in front. Many models have been developed to describe this longitudinal behaviour. For example, see Brackstone & McDonald (1999), Hoogendoorn & Bovy (2001) and Tampère (2004) for comprehensive overviews of car-following models. Three ‘classical’ types of car-following models are briefly presented below: stimulus-response models, safe distance models and psycho-physical models.

Stimulus-response models

This well-known group of car-following models assumes that drivers observe stimuli and react to these stimuli after some reaction time with a certain sensitivity. The stimulus can be defined by the speed difference between the leader and the follower. The response is the braking or the acceleration of the follower, delayed by an overall reaction time. The sensitivity of the response can be based upon driver characteristics or the relative distance between the leader and the follower. One of the first models was linear and could be attributed to Helly (1961). He expressed the acceleration of the follower as a linear function of the speed difference and the distance difference with respect to the leader. Nowadays, the so-called Gazis-Herman-Rothery (GHR) model developed by the General Motors group (Gazis et al., 1961) forms the basis of a set of stimulus-response models. Bexelius (1968) stated that a driver not only reacts to the vehicle driving directly in front of him, but also to the vehicle in front of that vehicle. So in his model the stimulus is not only defined by the speed difference between the first leader and the follower, but also by the speed difference between the second leader and the follower.

Safe distance models
This group of car-following models (also known as collision avoidance models) assumes that the following driver chooses his speed in such a way that he is able to bring his vehicle to a safe stop in case of a sudden stop of the leading driver. One of the first formulations of these models dates to Kometani and Sasaki (1959). Since then, a number of variants of this model have been developed. For example, Gipps (1981) assumed that the driver chooses his speed such that he is able to keep the minimum distance at standstill whenever the leader brakes at the maximum desired deceleration rate. The most important changes included an additional ‘safety’ reaction time and maximum braking rates of the leader and the follower.

Psycho-physical models
This group of car-following models (also known as action point models) uses thresholds or action points where the driver changes his behaviour. Drivers are assumed to react to changes in relative speed or spacing with the leader only when these thresholds are reached. The ability to perceive speed differences and estimate distances varies widely among drivers, as well as the desired speed and safety distance. Clearly, this complicates the estimation and calibration of the thresholds associated with this group of car-following models. Two well-known psycho-physical models are those developed by Wiedemann (1974) and Fritzsche (1994).

Lateral models
Lateral control actions – in particular lane-changing – can act as initial disturbances that might trigger a traffic breakdown. For example, the merging process near bottlenecks such as on-ramps or lane drops can be the direct cause for traffic breakdown. Also, lane-change manoeuvres in critically dense traffic can cause ‘phantom’ jams (i.e. spontaneous jams without any apparent bottleneck). Despite its significance, lane-changing has not been studied as extensively as car-following. This is mainly due to the scarcity of reliable data and the latent nature of lane-change behaviour. Three lane-changing models are briefly discussed below.

Gipps (1986) presented a framework for lane-changing decisions in urban driving situations including the influence of traffic signals, obstructions and different vehicle types (e.g. heavy vehicle) on the driver’s lane selection. A lane-change is modelled as a decision process analysing the necessity of the lane-change (e.g. determined by the route), the desirability of the lane-change (e.g. to reach the desired speed) and the feasibility conditions for the lane-change that are local, depending on the location of the vehicle on the road network.

Ahmed (1999) proposed a lane-change model based on the following three steps: (a) decision to consider a lane-change, (b) choice of a target lane and (c) acceptance of a gap in the target lane. A distinction is made between mandatory and discretionary lane-changing situations. A driver performs a mandatory lane-change (MLC) when he must leave the current lane (e.g.

lane drop) and performs a discretionary lane-change (DLC) when he perceives the driving conditions in the target lane to be better, although a lane-change is not required. Drivers are expected to be more aggressive under MLC situations compared to DLC situations. The model captures this behaviour by allowing different parameters for the gap acceptance model. Furthermore, a forced merging model is developed that captures merging in congested traffic conditions.

The more recently developed lane-change model by Hidas (2005) also includes the merging process during congestion. The model includes three types of lane-change manoeuvres: free, forced and cooperative. The main difference between these manoeuvres is the nature of interaction between the driver and the new follower on the target lane. In a free lane-change, there is no interaction at all. In a forced lane-change, the interaction is mainly one-way: the driver forces the follower to slow down and create a gap to merge into. In a cooperative lane-change, the interaction is two-way: the driver indicates his lane-change wish, the follower reacts to that by cooperating and slowing down, the driver realises that the follower gave way and he executes the lane-change.

Validity of models

It is important to test whether a model reasonably approximates reality by validating and calibrating it (Benehokal, 1991; Wu et al., 2003). Validation is the process of determining the extent to which the model is able to portray actual traffic behaviour as specified by the underlying theories and field data. Calibration involves the review and adjustment of parameter settings to reflect the local traffic conditions being modelled. This is considered a difficult task, because parameters are not directly observable from common traffic data, they are not transferable to other situations (e.g. locations) and driving behaviour is variable in time and space (Hoogendoorn & Ossen, 2005). Particularly, the lack of microscopic data prohibited for a long time the assessment and adaptation of driving behaviour models. Recently, progress has been made by using data of individual drivers collected via cars equipped with Differential Global Positioning System (dGPS) and via remote sensing with cameras attached to buildings or helicopters. In particular the validity of car-following models was studied with these new data. These models are not only an important part of microscopic traffic flow modelling, they also form the basis of the functional definitions of driver support systems, such as Adaptive Cruise Control (ACC) (Brackstone et al., 1999) and in our case the Congestion Assistant.

Brockfeld et al. (2004) tested ten different car-following models with data collected via vehicles equipped with dGPS on a test track in Japan. The deviations between measured and simulated time headways of two consecutive cars were used to calibrate and validate the models. No model appeared to be significantly better than any other model. Therefore, the authors recommended using simple models, because complex models with more parameters likely would not produce better results.

Ossen et al. (2006) studied the performance of car-following models during congested traffic flow conditions. They used vehicle trajectories on a motorway collected from a helicopter, containing detailed information about the movements of a large number of individual cars and their interactions. Seven car-following models were evaluated focusing on inter-driver differences. No ‘universal’ model could be selected out of the seven models that yielded good results for all drivers, due to large inter-vehicle differences. The authors assumed that a mix of car-following models and parameter settings should be used to describe congestion.

Furthermore, the parameters should be ‘validatable’ and include distance and relative speed to the leader and driver responses to multiple leaders.

7.3.3 Microscopic traffic flow models

The above-mentioned driving behaviour models can be incorporated into a computer program to simulate real-world traffic flows. Generally, these microscopic traffic flow models (also called microscopic simulation models) calculate each vehicle’s position, speed and acceleration on a predefined road network from driver behaviour and vehicle characteristics for each time step. Most models describe the traffic flow in two formats: (a) numerical and (b) graphical (Lieberman & Rathi, 1997). The numerical results provide detailed quantitative descriptions of what is likely to happen, while the graphical representations provide an understanding of how the traffic flow is behaving. The graphical representations can explain why the numerical results were produced, thus being a powerful tool for analysing simulation results.

A large number of microscopic traffic flow models have been developed so far. For example, Bernauer et al. (1997) analysed 32 simulation models within the framework of the SMARTEST project. The models differed from each other with respect to the area of application (e.g. urban network, motorway network), the scale of application (e.g. ranging from less than a hundred to over a million vehicles), the objects and phenomena modelled (e.g. queues, pedestrians, weather conditions) and the indicators for different objectives (e.g. efficiency, safety). Examples of microscopic traffic flow models are:

- IDM (Treiber et al., 2000): this research tool is particularly developed to simulate longitudinal driving behaviour on congested motorway sections. It is able to simulate driver support systems, such as ACC.
- MIXIC (Van Arem et al., 1997): this research tool is specifically developed for the assessment of the impacts of modern telematic technologies in traffic, such as driver support systems. It includes a large number of measures of traffic efficiency, traffic safety and emissions. The simulation of bottlenecks is limited, because only lane drops can be simulated. Recently, MIXIC was incorporated into the simulation environment ITS Modeller (see also below).
- Paramics (Quadstone, 2005): this commercial tool offers an environment for microscopic traffic simulation on urban and motorway networks. Basically, it is not suitable for the simulation of driver support systems, because the driving behaviour models are largely implemented as ‘black boxes’.
- SIMONE (Minderhoud, 1999): this research tool is specifically designed to study the traffic flow effects of different ACC systems. It is able to represent manual and assisted driving in free flow as well as congested traffic conditions. It can simulate motorway bottlenecks, such as on-ramps and weaving sections, and includes alternative car-following behaviour during congestion.
- VISSIM (PTV, 2006): this commercial tool offers an environment for the simulation of a wide variety of urban and motorway applications, integrating public and private transportation. Basically, it is not suitable for the simulation of driver support systems, because the driving behaviour models are largely implemented as ‘black boxes’.

Choice for ITS Modeller

To study the impacts of the Congestion Assistant on motorway traffic, the simulation tool to be used should meet the basic requirements mentioned in Section 7.3.1. It should also be flexible as to incorporate driving behaviour of vehicles equipped with the Congestion

Assistant. Practical issues concern the availability of the tool (e.g. in terms of a licence) and the technical support at hand. The simulation environment ITS Modeller developed by Versteegt et al. (2005) meets these requirements and was therefore used in this research project. It needs to be connected to a microscopic traffic flow model. Currently, it is coupled with Paramics. The ‘black box’ models of Paramics are overruled by the ITS Modeller. To this end, the ITS Modeller uses models that are largely based on those in MIXIC. More information about the ITS Modeller can be found in the next chapter.

7.4 Effects of driver support systems on the traffic flow

Many people believe that road networks without congestion belong to an ideal state that will never be reached. However, several possibilities are present to help mitigate the effects of congestion. Since expansions of the infrastructure are expensive and not always desirable, nowadays more focus is put onto getting the most out of existing facilities. For example, driver support systems, such as the Congestion Assistant, are expected to improve the traffic process by reducing undesirable driving behaviour. This section discusses the results of earlier research into driver support systems that are related to the functions of the Congestion Assistant. The focus is on the impacts of these systems on the traffic flow in terms of traffic efficiency and traffic safety.

7.4.1 Adaptive Cruise Control

It is expected that particularly Adaptive Cruise Control (ACC) can compensate for the unfavourable human behaviour that causes congestion (Treiber et al., 2006). An ACC system can control the speed and distance to the preceding vehicle more accurately than human drivers can. Drivers sometimes brake harder than necessary or unintentionally change their speed (e.g. due to driver distraction), which can induce a traffic jam in dense traffic. ACC can eliminate these driving behaviours. Besides, an ACC system can take away the spacing that is needed because of the reaction time of drivers. Therefore, more road capacity can be created, because vehicles can follow each other more closely at high speeds. Accordingly, no traffic efficiency benefits will be obtained if ACC systems imitate average car-following behaviour.

One of the first publications on potential traffic flow effects of ACC systems is by Broqua (1992). He studied the changes in traffic flow induced by the introduction of ACC systems that work with a time headway of 1.0 s. Microscopic simulation results on a two-lane motorway stretch showed that the system led to an increase in traffic efficiency. When 40% of the vehicles were equipped with the system, gains of 10% in density and 15% in throughput were found. Zwaneveld & Van Arem (1997) concluded in their literature review that ACC systems in mixed traffic conditions are likely to outperform manual traffic. The systems can result in safety and stability improvements by decreasing the variance in speed and the number of shockwaves. Improvements in traffic efficiency can be gained depending on the time headway setting and the equipment rate of the systems. Minderhoud (1999) studied the impacts of different ACC systems on motorway traffic flow with the microscopic simulation model SIMONE. He concluded that ACC systems with a time headway setting below 1.2 s increased the critical density and the road capacity. Furthermore, the capacity gains increased when the penetration rate of ACC systems increased. The majority of the ACC systems tested did not affect traffic safety compared to the reference situation with no equipped vehicles. Only one particular ACC system showed unsatisfactory Time-To-Collision (TTC) values. This was probably due to the time headway setting of 0.8 s in combination with the need for driver intervention if the speed dropped below the minimum supported speed of 30 km/h.

7.4.2 Stop & Go

Compared to ACC systems with a limited speed range, more is expected from so-called Stop & Go systems, which particularly support the driver in congested traffic situations. One of the ACC systems tested by Minderhoud (1999) was especially designed for assisting the driver in stop-and-go conditions with a speed range of 0 to 60 km/h. However, this system showed a negative impact on road capacity, most likely because of the relatively large time headway setting of 1.2 s.

The effects of Stop & Go in combination with ACC on urban motorways and urban arterial roads were studied in the STARDUST project (TRG, 2004). The simulation results showed that ACC systems solely had little positive impacts on traffic efficiency in terms of decreased travel times. However, Stop & Go systems could contribute to the increased traffic efficiency significantly. This was highly dependent on the traffic conditions encountered: the more severe the congestion, the more benefits of the Stop & Go. Also positive impacts on traffic safety in terms of decreased numbers of small time headways and small TTC values were found.

Within the Congestion Assistant project of the German research initiative INVENT, Benz et al. (2003) concentrated on raising the congestion outflow by examining different time headway settings of a Stop & Go system. Microscopic simulation results showed an increased traffic flow with a time headway of 1.0 s, because this setting is smaller than the average time headway applied by unsupported drivers when leaving the traffic jam.

7.4.3 Cooperative systems

The functionality of driver support systems can be enhanced when vehicles exchange information with each other or the road. Hogema et al. (2002) examined the traffic flow effects of the so-called dynamic Intelligent Speed Adaptation (ISA). The ISA system communicates with the roadside to determine the actual ISA speed limit based on the traffic state near a lane drop. Microscopic simulation results with MIXIC showed a decrease in throughput combined with positive effects on safety. This decrease in throughput is probably due to the fact that drivers cannot accelerate above the speed limit, so that the merging process becomes less efficient.

Based on vehicle-vehicle communication, the WARN system receives warnings from other traffic, for example vehicles in traffic jams. The effects of the WARN system on a motorway were studied with the microscopic simulation model VISSIM (Benz, 2002). The system resulted in a more homogeneous traffic flow expressed by a reduction in the numbers of hard braking manoeuvres and small TTC values. Already with a 10% equipment rate of the WARN system, the equipped vehicles influenced the behaviour of non-equipped vehicles. So the non-equipped vehicles can take advantage of the information that vehicles equipped with the WARN system have.

The Cooperative Following (CF) system is another example of cooperative systems that can affect the traffic flow (Van Arem et al., 2003). The CF system uses automated longitudinal control combined with vehicle-vehicle communication to anticipate severe braking manoeuvres in emerging shock waves with the aim of smoothening traffic flow and enhancing traffic safety. The results of a small-scale simulation showed that vehicles equipped with CF quickly responded to downstream braking manoeuvres which led to safer headways at a platoon level. However, besides these positive effects, the current CF settings sometimes led to unstable behaviour caused by specific variations and peaks in the acceleration. This shows that the settings of a system like CF are crucial for the adequate functioning of it.

The impacts of Cooperative Adaptive Cruise Control (CACC) on traffic flow characteristics were studied by Van Arem et al. (2006). Through the exchange of information with its predecessor, a CACC system can follow this predecessor more closely. MIXIC was used to examine the traffic flow effects of CACC working with a time headway of 0.5 s for a motorway merging scenario from 4 to 3 lanes. The results showed an improvement of traffic flow stability expressed by fewer shockwaves and smaller standard deviations of speed, and a slight increase of traffic efficiency indicated by higher queue discharge flows. CACC systems especially led to an improved traffic flow during conditions with a high traffic volume. Then there is more interaction between vehicles and thus more CACC platoons can be formed. However, such close-following platoons also showed negative effects on traffic safety in the merging process, because they prevented other vehicles from cutting in.

Kesting et al. (2007) proposed a 'jam-avoiding' ACC strategy that adapts the ACC driving style dynamically to the traffic situations determined by vehicle-vehicle or vehicle-infrastructure communication (Schönhof et al., 2007). When approaching a traffic jam, the comfortable deceleration level of the ACC system decreases to increase the traffic safety by earlier braking. When arriving at the bottleneck section and when leaving the traffic jam, the maximum acceleration increases while the time headway decreases, both to increase the bottleneck capacity. Microscopic simulation results with IDM showed that already a small amount of 'traffic-adaptive' ACC vehicles improved the traffic stability and performance and led to a drastic reduction of traffic congestion.

7.5 Implications for this research

One of the aims of this research project is to study the impacts of our Congestion Assistant on the traffic flow. This system is not available on the market, which strongly limited the selection of a suitable evaluation methodology. For example, a large-scale field test was impossible. A traffic simulation study is therefore an appropriate evaluation method. Since the Congestion Assistant intervenes in the way the driver controls his vehicle, a microscopic simulation approach was chosen. The simulation environment ITS Modeller coupled with Paramics and largely based on MIXIC was used in this research. A great advantage of the ITS Modeller over other traffic simulation tools is the transparency of the underlying models, so that the algorithms defining new systems, such as the Congestion Assistant, can be easily implemented. Contrary to some of the simulation tools used in the studies above, the ITS Modeller was calibrated and validated for our research into the Congestion Assistant.

This chapter pointed out that individual driver behaviour influences to a large extent the onset, course and dissipation of a traffic breakdown. The results of earlier research revealed that driver support systems similar to the functions of the Congestion Assistant can reduce the sometimes unwanted driving behaviour to mitigate congestion. Particularly systems that stimulate early braking when approaching a traffic jam, such as the dynamic ISA and the traffic-adaptive ACC, showed positive effects on traffic safety. Traffic efficiency was especially improved by ACC systems that operate with a relatively small time headway. Adding a Stop & Go function to the ACC system (i.e. extending the speed range) made a considerable contribution to these positive effects on the throughput of traffic. An innovative aspect of our study is the combination of driver support systems like the ones above in one system, namely the Congestion Assistant.

Following from the literature review, it is expected that the Congestion Assistant can contribute to the prevention of traffic breakdown and the dissipation of congestion. Particularly the Active pedal is supposed to homogenize the traffic flow when approaching a jam and reduce the congestion inflow. The Stop & Go can homogenize the traffic flow in the jam and raise the congestion outflow. These expectations were tested by examining the influence of vehicles equipped with the Congestion Assistant on the traffic performance. Not only the assessment of the total Congestion Assistant was of interest, but also the assessment of the separate functions. Several variants of the Congestion Assistant with different equipment rates were examined. Several measures related to flow, speed, acceleration and TTC were taken into account. The next chapter will discuss the set-up of the traffic simulation study and the impacts of the Congestion Assistant on the traffic flow.

Chapter 8

Impacts of the Congestion Assistant on the traffic flow

A traffic simulation study was conducted to investigate the impacts of the so-called Congestion Assistant on the traffic flow in terms of traffic efficiency and traffic safety. This chapter describes the set-up of the study and discusses the results. Variants of the Congestion Assistant with different equipment rates on a four-lane motorway with a lane drop were analysed. The Congestion Assistant reduced the amount of congestion significantly, especially due to the Stop & Go. This function led to more efficient car-following behaviour when driving in and leaving a traffic jam by maintaining smaller headways and eliminating the reaction time of drivers. The Active pedal of the Congestion Assistant hardly influenced traffic efficiency, rather it affected traffic safety through a safer approach to a jam.

8.1 Introduction

This chapter focuses on the assessment of the Congestion Assistant with respect to traffic efficiency and traffic safety. For this purpose, a microscopic traffic simulation study was carried out. The Congestion Assistant supports the driver during congested traffic situations on motorways. In this study it consisted of the following functions:

- Active pedal: while approaching the traffic jam, the driver could feel a counterforce of the gas pedal when the speed was too high according to the system.
- Stop & Go: while driving in the traffic jam, the longitudinal driving task was taken over by the system.

The Warning function of the Congestion Assistant (see Chapter 6) appeared not to affect driving behaviour, so this function was not taken into account in the traffic simulation study.

Driving with the Congestion Assistant could potentially lead to a safer and more efficient traffic flow. However, this is largely dependent on how the system performs compared to ‘normal’ drivers. In other words: to what extent is the Congestion Assistant able to compensate for the unfavourable human behaviour that (also) causes congestion? In this traffic simulation study hypotheses were tested with respect to changes in traffic flow performance due to driving with the Congestion Assistant. The main hypotheses were as follows:

- The Active pedal will smooth the traffic flow towards the traffic jam by earlier and calmer decelerations. This will reduce the congestion inflow, which in turn will have positive effects on the dissipation of the jam.
- The Stop & Go will lead to car-following at closer headways with less variation and it will better anticipate leading vehicles. These behaviours will increase the congestion outflow, which in turn will have positive effects on the dissipation of the jam.
- By combining the Active pedal and the Stop & Go, it is expected that the effects on traffic efficiency will be largest.
- Positive effects on the dissipation of jams will increase with increasing penetration rates of the Congestion Assistant. However, there could be a turning point for the Active pedal, because higher penetration rates might lead to new jams induced by ‘too early’ braking actions.
- Both the Active pedal and the Stop & Go will lead to a more stable and homogeneous flow, which in turn will have positive effects on traffic safety.
- Positive effects on traffic safety will increase with increasing penetration rates and by combining the Active pedal and the Stop & Go.

The following section deals with the specification of the Congestion Assistant in the ITS Modeller, which is the simulation environment used in this study. After that, the set-up of the traffic simulation study is described, including the variants of the Congestion Assistant, the equipment rates of the system and the motorway bottleneck that were taken into account. The calibration of the reference situation is also discussed in this section. Next, the results of driving with the system on congestion dynamics in terms of traffic efficiency and traffic safety are presented. These results are then discussed in the light of the hypotheses stated above. Furthermore, the methodology used is considered. The chapter ends with conclusions.

8.2 Specification of Congestion Assistant in ITS Modeller

8.2.1 ITS Modeller

The ITS Modeller is a modelling environment in which intelligent cooperative vehicle-infrastructure systems can be modelled, tested and evaluated for their impacts on traffic efficiency, traffic safety and the environment (Versteegt et al., 2005). The environment has been build in the Java programming language and uses a modular set-up so that new models can be easily added. The ITS Modeller has to be connected to a commercially available traffic simulation tool for the road network and the generation of vehicles. Paramics was used in this study (Quadstone, 2005).

Each time step of 0.1 s, the ITS Modeller calculates new vehicle positions and states by a driver and a vehicle model. Next to these models, the ITS Modeller has an ITS model that describes the working of intelligent systems, such as a driver support system. The combined models produce the new vehicle acceleration and the decision to change lane or not. In each iteration, the driver model – and if applicable also the ITS model – produce driver actions, such as the desired acceleration and the new positions of the gas and brake pedals. Together with other input, such as vehicle characteristics and road geometry, these driver actions are then used by the vehicle model to generate the resulting vehicle acceleration and position of the vehicle. The different components of the ITS Modeller (see Figure 8.1) are discussed below. Most focus is put onto the longitudinal driver model, because this model forms the basis of the functional definition of the Congestion Assistant (see Section 8.2.3) and it has a large impact on the formation of traffic jams (see Section 8.3.4).

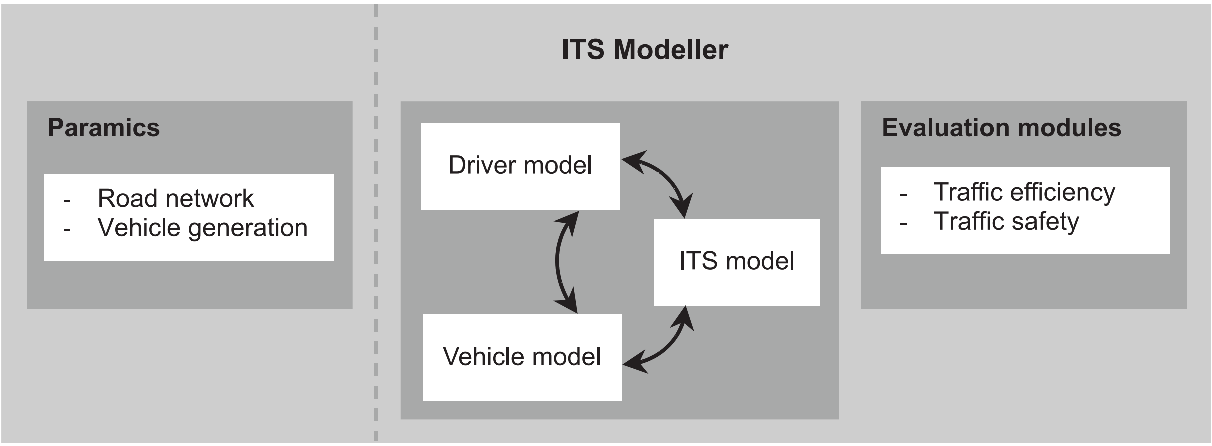


Figure 8.1: Components of the simulation environment ITS Modeller

Longitudinal driver model

The longitudinal driver model describes the driver’s actions with respect to longitudinal vehicle control. This model distinguishes free driving and car-following behaviour. In each iteration, a desired acceleration is calculated for both situations. The most restricted one is used as the resulting desired acceleration. Several driver types can be modelled that differ in their longitudinal driving behaviour. In this study, drivers of a passenger car and a truck were taken into account.

Free driving

In the free driving situation, the driver attempts to reach or maintain his desired speed within certain boundaries. The desired speed indicates the speed that would be maintained in the absence of other traffic and is drawn from a normal distribution. The mean and standard deviation of the free driving speed have been determined from loop detector measurements (Van Arem et al., 1997). For passenger car drivers the mean desired speed is set at 121 km/h (SD = 12 km/h) and for truck drivers at 86 km/h (SD = 6 km/h). The desired acceleration for free driving is computed on the basis of the difference between the current speed and the desired speed:

$$a_{ref\_v} = r \cdot \left(v_{ref} - v\right) \tag{8.1}$$

With

a_{ref_v}	desired acceleration for free driving (m/s^2)
v_{ref}	desired speed (m/s)
v	current speed (m/s)
r	relaxation factor (1/s) (default set at 0.4/s)

If the current speed deviates more than a given proportion (set at 3%) from the desired speed, the desired acceleration is made proportional to the speed error. The resulting desired acceleration is limited within the boundaries for comfortable acceleration and deceleration, which are set at 3 m/s^2 and -5 m/s^2 respectively.

Car-following

In the car-following situation, the driver has to adjust his speed and/or following distance with respect to traffic ahead. The model is based upon the assumption that drivers try to keep the relative speed to the predecessor zero and simultaneously attempt to keep the distance headway at a desired value. In addition to the original model, also the relative speed to the vehicle ahead of the predecessor is taken into account. The desired distance headway increases according to a quadratic function of the current speed:

$$d_{ref} = c_1 + c_2 \cdot v + c_3 \cdot v^2 \tag{8.2}$$

With

d_{ref}	desired distance headway (m)
v	current speed (m/s)
c_1, c_2, c_3	constant factors (default set at 3, 0.25 and 0.02 respectively)

The desired acceleration for car-following is denoted by a linear combination of the relative speeds to the predecessor and the pre-predecessor and the deviation from the desired distance headway:

$$a_{ref\_d} = c_d \cdot \left(d\left(t - t_r\right) - d_{ref}\right) + c_{v\_p} \cdot v_{rel\_p}\left(t - t_r\right) + c_{v\_pp} \cdot v_{rel\_pp}\left(t - t_r\right) \tag{8.3}$$

With

a_{ref_d}	desired acceleration for car-following (m/s^2)
$d\left(t - t_r\right)$	distance headway at current time t minus reaction time t_r (m)

d_{ref}	desired distance headway (m)
$v_{rel\_p}(t-t_r)$	relative speed to predecessor at current time t minus reaction time t_r (m/s)
$v_{rel\_pp}(t-t_r)$	relative speed to pre-predecessor at current time t minus reaction time t_r (m/s)
c_d	constant factor for distance deviation (default set at 0.3)
c_{v_p}	constant factor for speed deviation predecessor (default set at 1.5)
c_{v_pp}	constant factor for speed deviation pre-predecessor (default set at 0.2)

Equation 8.3 is based on the original Helly model (see Section 7.3.2). It is extended by including the speed difference with the pre-predecessor as an additional stimulus, so that the driver can better anticipate the downstream traffic situation (Klunder et al., 2006). As can be seen, the reaction time of the driver is taken into account when evaluating the distance headway and the relative speeds. Like the desired speed, the reaction time is drawn from a normal distribution. For car drivers a mean value of 0.3 s (SD = 0.05 s) is used and for truck drivers 1.0 s (SD = 0.3 s) (Van Arem et al., 1997). Note that these values are exclusive of aspects like delays for moving the foot between the gas and brake pedals and perception thresholds. These aspects are modelled separately.

Lateral driver model

The lateral driver model describes the driver's actions with respect to lateral vehicle control. This model distinguishes free lane-changing and mandatory lane-changing and includes similar steps as the lateral models mentioned in Section 7.3.2. The free lane-change model represents overtaking when a slower predecessor is forcing the driver to reduce his speed below his desired speed. The mandatory lane-change model is applied if a driver is aware that the lane he is driving on does not lead to his destination, does not continue on the next link, or is not accessible to him. Generally, the free lane-change model is applied, unless a driver has to make a mandatory lane-change.

Free lane-changing

The first step of the free lane-change model is to determine whether the driver decides to execute a lane-change manoeuvre to the right or left lane. Secondly, when a lane-change decision has been taken, a simple procedure is used to simulate the actual lane-change execution. Rules are specified for 'want to change' and 'perform the change', both to the left and to the right. The rules for 'want to change' include a comparison of the current speed with the desired speed and with the speed of the predecessor in the current lane. Also the vehicle's current acceleration with respect to the maximum comfortable acceleration and deceleration is evaluated. The rules for 'perform the change' refer to the safety of the intended manoeuvre, determined by a sufficiently large gap in the target lane. A time delay is used to simulate the actual lane-change execution. When a lane-change decision has been taken, it is executed not immediately, but only after this delay. For gaining speed advantage, the free lane-change model primarily considers lane-changes to the left. However, the model was adapted to introduce lane-changes to the right in congested traffic conditions to gain speed advantage (i.e. when the lane to the right moves faster than the current lane). This adaptation is applicable as soon as the current vehicle speed is below a threshold, set at 70 km/h. The safety of the manoeuvre is evaluated using the relative speed with respect to the new successor.

Mandatory lane-changing

The mandatory lane-changing process consists of a number of steps. First, the driver has to perceive the forthcoming situation and choose a target lane. The simulated road network might include discontinuity points. Such points imply that the current lane of the driver will not remain to be available for him. For each discontinuity point, there is a pre-warning distance. In this study, the pre-warning distance was set at 1150 m, which was based on the Dutch standard distance of 1000 m to announce a lane drop and a perception distance of 150 m. As soon as the driver passes the pre-warning distance, the target lane is determined. Next, the driver has to decide on the intention to change lane. There is a distance at which the driver will start to undertake action to change lane. If a mandatory lane-change is needed, the intention to change is drawn from a normal distribution cut off between the pre-warning distance and some distance before the discontinuity point. Then, the driver has to scan for an appropriate gap in the adjacent lane and control the relative speed and position. The driver controls his speed to the speed of the adjacent lane. If a gap is found, it is checked whether it is large enough. If that is the case, fine-tuning of the relative position takes place. When approaching the discontinuity point, the driver will gradually accept shorter distance headways. Also the minimum required gap decreases with decreasing distance to this point. At the same time, the fierceness with which the driver tries to control deviations from his intended relative distance or speed increases. Finally, the driver performs the lane-change if the gap is large enough, the relative position to the gap is right and the angular speed with respect to the new predecessor and successor are less than a certain threshold (default set at 0.021 rad/s).

ITS model

The ITS Modeller is particularly suitable for modelling the impacts of roadside and in-vehicle systems as well as cooperative systems. These systems can be implemented in the ITS Modeller as a new ITS model. The ITS model describes the behaviour of the system in question and the interaction between the driver and the system. The system may take over certain tasks from the driver. This can be represented by adapting the equations of the longitudinal and lateral driver models. If the driver is overruled by the system, the output of the ITS model is directly given to the vehicle model. Otherwise, the output is used by the driver model.

Vehicle model

The vehicle model describes the dynamic behaviour as a result of the interaction with the driver and the road, taking into account the ambient conditions. The input variables from the driver model are the positions of the gas and brake pedals. Together with these input variables, the vehicle model uses information about the characteristics of the vehicle, the road geometry, the condition of the road and the wind. The output of the model is an updated vehicle acceleration, which is used to calculate the new speed and position of the vehicle. Several vehicle types can be modelled that differ in their vehicle characteristics. In this study, passenger cars and trucks were taken into account.

Evaluation modules

The impacts of ITS systems, such as driver support systems, on the traffic flow can be evaluated by the evaluation modules of the ITS Modeller for throughput and safety. Both modules can provide a range of measurements. In this study, the following data on traffic efficiency and traffic safety were measured. For traffic efficiency: flow and speed, and for traffic safety: speed variation, Time-To-Collision (TTC) and acceleration behaviour (see also Section 8.3.5). The evaluation data can be retrieved per time interval (e.g. 1 minute) for cross-sections (i.e. detectors), links, routes and the whole network.

Paramics

The ITS Modeller functions as a shell for several commercially available traffic simulation tools. For this study, the ITS Modeller was connected to Paramics (Quadstone, 2005). This means that Paramics was used to build the road network, generate the vehicles and graphically represent the simulation. To release vehicles onto the network, Paramics calculates each time step the probability that a vehicle will be generated between pairs of origins and destinations. It then uses that probability against a randomly generated number from a so-called random seed to decide whether the vehicle will be released or not. The stochastic elements of the ITS Modeller (e.g. the desired speed) are connected to this random seed. To simulate the randomness of traffic behaviour, this study used a number of replications with different random seeds (see also Section 8.3.5). The behavioural models of Paramics are overruled by those of the ITS Modeller.

8.2.2 Conceptual design

Several steps had to be taken to implement the Congestion Assistant into the ITS Modeller. The conceptual design describes the functionalities of the Congestion Assistant taken into account in this traffic simulation study. The Congestion Assistant supports the driver during congested traffic conditions on motorways by a combination of informing, assisting and controlling functions. The information provided by the driving simulator experiment (see Chapter 6) was used as input for this traffic simulation study. The Congestion Assistant showed to affect the driver and his behaviour in the driving simulator experiment. These impacts could be attributed to the assisting and controlling functions, namely the Active pedal and the Stop & Go. This traffic simulation study therefore concentrates on the traffic flow impacts of these two functions. The participants in the driving simulator experiment drove with the Congestion Assistant in two visibility conditions: normal visibility and fog. However, the visibility condition did not show particular differences in the effects of the Congestion Assistant on driving behaviour. Therefore, only the normal visibility condition was taken into account in this traffic simulation study. In contrast to the Stop & Go, the driver could react to the possible force feedback of the Active pedal, namely by obeying or overruling it. The results of the driving simulator experiment showed that the participants did not always choose to obey the Active pedal. Unfortunately, no detailed information about when or why they sometimes decided to overrule the Active pedal was available. It was therefore assumed in this traffic simulation study that the driver would obey the Active pedal, thus not counteracting the 'ideal' driving behaviour when approaching a traffic jam.

In summary, based on the results from the driving simulator experiment with the Congestion Assistant, the main implications for this traffic simulation study were that:

- The Congestion Assistant consists of either the Active pedal or the Stop & Go, or a combination of both functions.
- The simulation runs take place during normal visibility conditions.
- The driver will obey the Active pedal.

8.2.3 Model specification

The next step of implementing the Congestion Assistant into the ITS Modeller comprised the model specification that outlines the mathematical algorithms used by the ITS Modeller to describe the working of the Active pedal and the Stop & Go. People driving with a Congestion Assistant consisting of a combination of both the Active pedal and the Stop & Go will display four types of driving behaviour when encountering a traffic jam (see Table 8.1).

Table 8.1: Four types of driving behaviour with Congestion Assistant

Type of driving behaviour	Explanation
1. Normal	Far before jam: driver displays 'normal' driving behaviour, thus without support from the Congestion Assistant or any other in-vehicle system
2. Active pedal	Before jam: driver displays driving behaviour according to the Active pedal which slows him down when approaching the traffic jam
3. Stop & Go	In jam: driver displays driving behaviour according to the Stop & Go which takes over the longitudinal driving task in the traffic jam
4. After Stop & Go	After jam: driver displays 'normal' driving behaviour except for his time headway which is smaller than before driving with the Stop & Go

The normal driving behaviour corresponds with the lateral and longitudinal driver models in the ITS Modeller (see Section 8.2.1). Driving behaviour according to the other three types are described below in more detail. It is assumed that the Congestion Assistant knows about the state of the traffic flow by means of vehicle-vehicle communication. Based on this information, the traffic jam can be located which is used for the activation of the Active pedal. This section ends with discussing the traffic jam detection.

Active pedal

The Active pedal is implemented in the ITS Modeller as a new ITS model. When the function is switched on (i.e. before the traffic jam), the Active pedal controls the behaviour of the vehicle. It computes a desired acceleration that represents the necessary deceleration for safely approaching the traffic jam. It is calculated based on the distance to the tail of the traffic jam, the current speed and the speed of the last vehicle in the tail of the traffic jam:

$$a_{ac} = \frac{v_j^2 - v^2}{2 \cdot x} \tag{8.4}$$

With

a_{ac}	desired acceleration by Active pedal (m/s^2)
v_j	speed of last vehicle in tail of traffic jam (m/s)
v	current speed (m/s)
x	distance to tail of traffic jam (m)

The desired acceleration by the Active pedal represents the deceleration needed to obtain the same speed as the last vehicle in the tail of the traffic jam. However, the Active pedal only helps with slowing down and thus gives a counterforce of the gas pedal if the desired acceleration is smaller than a threshold of -0.5 m/s^2. When the desired acceleration is larger than this threshold, it is assumed that the driver maintains an appropriate speed himself, so that no counterforce of the gas pedal is needed. Furthermore, the Active pedal is only working when the driver is less than a certain distance away from the jam. In this traffic simulation study, two variants of the Active pedal were investigated: one operating from 1500 m before the jam and the other operating from 500 m before the jam. The desired acceleration by the Active pedal is bounded by -1 m/s^2 which resembles deceleration by releasing the gas pedal. The Active pedal becomes inactive when the tail of the traffic jam is reached or when the Stop & Go overrules the Active pedal (in case the Congestion Assistant consists of both functions). Besides the desired acceleration by the Active pedal, the ITS Modeller also calculates two other desired accelerations which are related to free flow and car-following situations (see

Section 8.2.1). The actual desired acceleration will be the most restrictive one of all three desired accelerations.

Stop & Go

Comparable to the Active pedal, the Stop & Go was implemented in the ITS Modeller as a new ITS model. When the function is switched on (i.e. in the traffic jam), the Stop & Go controls the behaviour of the vehicle. The Stop & Go is assumed to be autonomous with respect to its (de)activation. This means that it does not use vehicle-vehicle communication to turn on or off. Instead, the Stop & Go will be active based on the current speed. If the vehicle drives at a speed of at most 50 km/h for a period of at least 3 seconds, the Stop & Go will become active. Next, if the vehicle will drive again at a speed of 70 km/h or more for at least 3 seconds, the Stop & Go will become inactive.

The Stop & Go algorithm of the Congestion Assistant is based on the algorithm described in Versteegt & Klunder (2005). The algorithm includes fine-tuned rules for some specific situations, such as convenient stopping, full stop and launch control. During the simulation runs, the Stop & Go is expected to be able to deal with all traffic situations. Therefore, the maximum acceleration was set at +3 m/s^2, while the maximum deceleration was set at -5 m/s^2. In this traffic simulation study, two variants of the Stop & Go were investigated: one with a desired time headway of 1.0 s and the other with a desired time headway of 0.8 s (see also Section 8.3.1). The Stop & Go tries to maintain the desired following distance as follows:

$$d_{st} = d_0 + t_{st} \cdot v \qquad (8.5)$$

With

d_{st}	desired distance headway by Stop & Go (m)
v	current speed (m/s)
d_0	safety margin (m) (default set at 3 m)
t_{st}	time headway setting (s)

Figure 8.2 shows that, at the same speeds, the Stop & Go applies a smaller distance headway than a ‘normal’ driver would do. This is due to the quadratic function of speed that manually driven vehicles use to determine their desired distance headway (see Equation 8.2). Note that the calibrated constant factors for manual driving are used (see Equation 8.10).

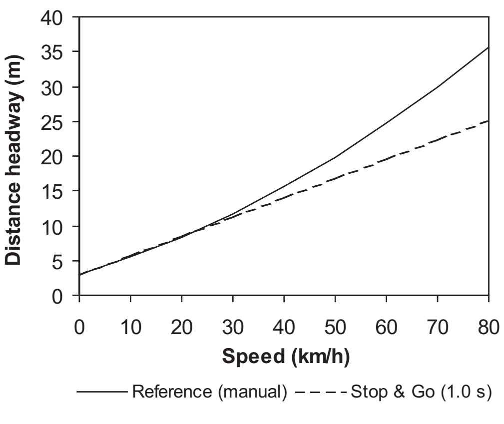


Figure 8.2: Car-following differences between vehicles equipped with and without Stop & Go

Next, the Stop & Go computes a desired acceleration that represents the necessary acceleration for safely driving in the traffic jam. It can be computed on the basis of the deviation from the intended speed or on the basis of the distance difference and speed difference between the own vehicle and the predecessor. The resulting desired acceleration is given by the most restrictive one and is limited between the maximum comfortable acceleration and deceleration, which are set at +3 m/s^2 and -5 m/s^2 respectively.

The desired acceleration by the Stop & Go based on the speed deviation is given by:

$$a_{st\_v} = r_{st} \cdot \left(v_{\text{int}} - v \right) \tag{8.6}$$

With

a_{st_v}	desired acceleration by Stop & Go (m/s^2)
v_{int}	intended speed of Stop & Go (m/s) (default set at 22.2 m/s ~ 80 km/h)
v	current speed (m/s)
r_{st}	relaxation factor (1/s) (default set at 0.4/s)

The desired acceleration by the Stop & Go is based on the distance difference and speed difference with respect to the predecessor:

$$a_{st\_d} = k_a \cdot \left(k_d \cdot \left(d - d_{st} \right) + k_v \cdot v_{rel\_p} \right) \tag{8.7}$$

With

a_{st_d}	desired acceleration by Stop & Go (m/s^2)
d	distance to predecessor (m)
d_{st}	desired distance headway by Stop & Go (m)
v_{rel_p}	relative speed to predecessor (m/s)
k_a	overall gain for Stop & Go controller
k_d	gain for distance error, depending on speed and distance error
k_v	gain for speed error, depending on speed

The overall gain for the Stop & Go controller depends on the time headway setting and is equal to 3.1 or 3.875 for a desired time headway of 1.0 s or 0.8 s respectively. More detailed information about the algorithm can be found in Versteegt & Klunder (2005).

After Stop & Go

When the traffic jam is dissipating and the Stop & Go switches off, the driver has to perform the whole driving task himself again. Results from the driving simulator experiment with the Congestion Assistant showed that participants followed more closely after the traffic jam when they had driven with the system. This change in driving behaviour was also incorporated into the ITS Modeller. Immediately after the deactivation of the Stop & Go, the desired time headway is assumed to be smaller than the one maintained by ‘normal’ drivers. This decrease is set at 0.4 s, based on the driving simulator experiment. A relaxation term is used so that the initial desired time headway gradually (i.e. linearly) evolves towards the normal desired time headway during a period of 60 s. The rest of the displayed driving behaviour after the deactivation of the Stop & Go is similar to the lateral and longitudinal models of normal drivers in the ITS Modeller.

Traffic jam detection
The Congestion Assistant should ideally know from each downstream vehicle whether it is located in a traffic jam or not. The Active pedal will use this information in its algorithm to slow down the driver if necessary. It is assumed that all vehicles can communicate with each other. Accordingly, the ITS Modeller checks the current speed and location of each vehicle in the network. This is done for each traffic lane individually and for each time step of 0.1 s. The traffic state on a lane is said to be jammed when more than 3 vehicles follow each other at a speed of at most 50 km/h for a period of at least 3 seconds. The last vehicle in the queue is used to determine the distance that a vehicle equipped with the Congestion Assistant is away from the traffic jam (see Equation 8.4).

8.3 Set-up of traffic simulation study

8.3.1 Variants of Congestion Assistant

Different variants of the Congestion Assistant were investigated, since it was expected that variation in system design might result in different traffic flow impacts. Each variant of the Congestion Assistant consists of either the Active pedal or the Stop & Go, or a combination of both functions. In total six variants were studied, see Table 8.2.

Table 8.2: Variants of Congestion Assistant consisting of Active pedal and/or Stop & Go

Variant	Active pedal	Stop & Go
1.	Active from 1500 m before jam	Time headway of 1.0 s
2.	Active from 500 m before jam	Time headway of 0.8 s
3.	Active from 1500 m before jam	-
4.	Active from 500 m before jam	-
5.	-	Time headway of 1.0 s
6.	-	Time headway of 0.8 s

The first variant of the Congestion Assistant is similar to the one studied in the driving simulator experiment. That is, the Active pedal is working from 1500 m before the tail of the traffic jam and the Stop & Go operates with a time headway of 1.0 s. Based on the recommendations from the driving simulator experiment, it was decided to also study variants of the Congestion Assistant with the Active pedal working from 500 m before the traffic jam. In this way, the Active pedal operates more as a final warning when the driver is approaching the jam at too high speed. Furthermore, variants of the system with respect to the time headway setting of the Stop & Go were examined. Small time headways imply a high traffic density, which is beneficial for the throughput of traffic. Therefore, variants of the Congestion Assistant with a Stop & Go time headway of 0.8 s were also included. Smaller values are considered uncomfortable and unsafe with respect to overrulable driver support systems (Minderhoud, 1999). Based on the two versions of the Active pedal and the Stop & Go, initially four ‘combined’ variants of the Congestion Assistant were analysed. However, only the two above-mentioned variants (i.e. variants 1 and 2) are further discussed in this chapter, since they represent the range of the observed results. To study the extent to which the Active pedal and the Stop & Go contribute to the traffic flow effects, also variants of the Congestion Assistant consisting of only one of the two functions were considered (i.e. variants 3 to 6).

8.3.2 Equipment rates

The magnitude of the traffic flow effects was expected to depend on the equipment rate of the Congestion Assistant in the vehicle fleet. Therefore, the impacts were studied at two levels of equipment penetration:

- 10% equipment rate
- 50% equipment rate

The six variants of the Congestion Assistant were studied at the two equipment rates, resulting in twelve experimental scenarios. In each experimental scenario three user classes were distinguished, namely:

- Passenger cars not equipped with the Congestion Assistant
- Passenger cars equipped with the Congestion Assistant
- Trucks not equipped with the Congestion Assistant

The situation in which no vehicles were equipped with the Congestion Assistant is referred to as the reference situation.

8.3.3 Motorway bottleneck

Being interested in the impacts of the Congestion Assistant, a clear bottleneck location on a motorway had to be chosen. Examples of such locations are on-ramps, weaving sections and lane drops. The ITS Modeller is currently well suited for modelling lane drops. Therefore, this motorway bottleneck was taken into account in this traffic simulation study. Loop detector data measured on the Dutch A12 motorway were used for the calibration of the reference situation (see next section). For this reason, the road geometry of the A12 served as input for the simulated road. Figure 8.3 shows the road geometry of the simulated road consisting of a four-lane motorway segment with a 120 km/h speed limit. The total length of the segment was about 6 km with a lane drop from 4 to 3 lanes (i.e. left lane drops) after about 4 km. The road geometry of the A12 consists of more elements, such as ramps and Variable Message Signs above the road, but these elements were not taken into account in this study for reasons of complexity.

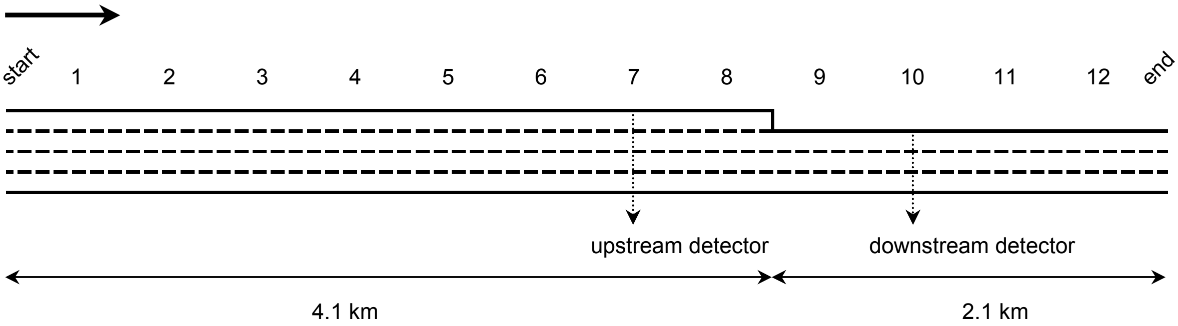


Figure 8.3: Road geometry of four-lane motorway with lane drop

The motorway segment was split up into 14 links: the start link and the end link were 100 m each, while links 1 to 12 were 500 m each. A left lane drop was modelled in between links 8 and 9. The driver was given a pre-warning of the lane drop at 1150 m before the transition from 4 to 3 lanes. Loop detectors that measured traffic data aggregated every minute were located in the middle of links 3 to 12. The detector at 750 m before the lane drop is called ‘upstream detector’, while the detector at 750 m after the lane drop is called ‘downstream detector'. Two detectors were added at 700 m before and 1000 m after the lane drop to simulate the detectors on the A12 motorway used for the calibration and validation process.

8.3.4 Calibration of reference situation

When using a microscopic traffic simulation tool such as the ITS Modeller, it is important to check the model against reality by calibrating and validating it. The calibration and validation in this study concerned the situation in which no vehicles were equipped with the Congestion Assistant, also called the reference situation.

Field data

The reference situation was calibrated using measured loop data on a segment of the Dutch A12 motorway between Utrecht and The Hague near Woerden. Here, the left lane drops so that the motorway changes from 4 to 3 lanes (see Figure 8.4). The data concerned 1-minute measurements of speeds and flows collected between 15:01-17:00 h on Tuesday 09 May 2006. The validation was done using the same type of data collected on Wednesday 10 May 2006. On both days, the traffic was first free flowing, while later on traffic jam formation occurred due to the lane drop. Next to the congestion build-up, these days were selected because: (a) the weather was good, (b) there were no accidents or events, (c) there was no holiday and (d) the detectors were available and working well.

Figure 8.4: Lane drop on Dutch A12 motorway near Woerden

The traffic demand used in the simulation runs was based on 5-minute flow data collected between 14:46-17:15 h on Tuesday 09 May 2006 (see Figure 8.5). These data were measured by the first detector after the on-ramp from Woerden, about 1200 m upstream of the lane drop. Two demand profiles were created in Paramics (from 14:46-16:00 h and from 16:01-17:15 h) to simulate the traffic demand. The percentage of heavy trucks on the A12 road segment was 7 to 8% on Tuesdays and Wednesdays in May 2006. The vehicle fleet in the simulation runs therefore consisted of 93% passenger cars and 7% trucks.

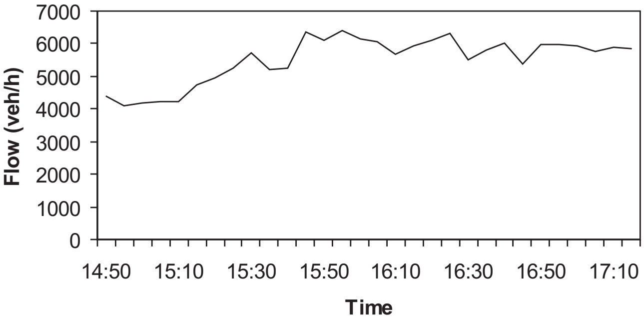


Figure 8.5: Traffic flow on A12 about 1200 m upstream of lane drop (5-minute data)

The simulation runs of the ITS Modeller were judged on the following points:

- The onset of congestion due to the lane drop by comparing the model results with the field data of the A12 about 700 m upstream of the lane drop
- The recovery from this congestion after the lane drop by comparing the model results with the field data about 1000 m downstream of the lane drop
- Lane-change behaviour and merging process near the lane drop by visually inspecting the graphical representations of the traffic flow

Lane-changing parameters

The first test runs with the default parameter settings of the ITS Modeller showed that the model could be improved, because no satisfactory congestion due to the lane drop was found. Adapting the lane-changing parameters did not have much influence on the simulation results. Only two constant factors of the mandatory lane-change model were changed to better represent the lane-change behaviour near the lane drop. These factors concerned the distance at which the driver will start to undertake action to change lane:

$$x_{\mathrm{int}} = x_{warn} \cdot \left(p_1 + random \cdot p_2\right) \tag{8.8}$$

With

x_{int}	distance at which driver starts to decide on intention to change lane (m)
x_{warn}	distance at which driver knows about discontinuity (e.g. lane drop) (set at 1150) (m)
$random$	draw from normal distribution (mean = 0.5, SD = 0.3), truncated at 0 and 1
p_1	constant factor (set at 0.25, default at 0.75)
p_2	constant factor (set at 0.75, default at 0.25)

The constant factors were adapted, so that compared to the default settings, the driver approaches the lane drop closer before he actually changes lane. This particularly agrees with congested traffic conditions in which drivers tend to continue driving on their lane until the end of it comes very near.

Car-following parameters

The calibration then focused on the car-following parameters. These parameters are expected to have a large impact on the formation of traffic jams. Besides, empirical data of the A12 is available to adjust these parameters. The calibration first concentrated on the constant factors in the equation that describes the desired distance headway:

$$d_{ref} = c_1 + c_2 \cdot v + c_3 \cdot v^2 \tag{8.2}$$

To estimate the constant factors, speeds and densities on the four lanes of the A12 were used. First, the densities were approximated by the ratio of flow to speed using measurements collected about 700 m upstream of the lane drop between 14:46-17:15 h on Tuesday 09 May 2006. Then, density-speed plots per lane were made, including the best fitting trendline for the density-speed relation (see Figure 8.6).

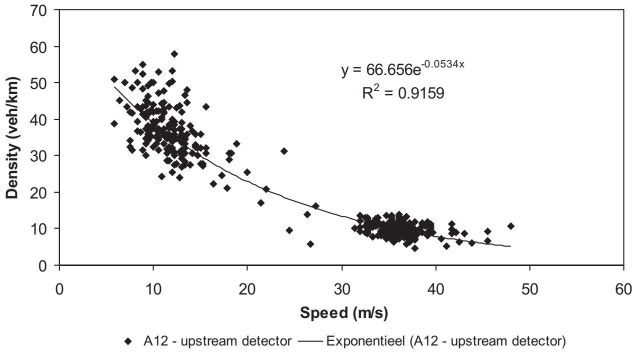


Figure 8.6: Density-speed relation for lane 4 (right) based on data from A12

The relation between density and desired distance headway can be described by:

$$1000 = k \cdot \left(veh_l - d_{ref}\right) \tag{8.9}$$

With
k = density (veh/km)
veh_l = vehicle length (m)
d_{ref} = desired distance headway (m)

The obtained density-speed relation was substituted into Equation 8.9 and solved for the desired distance headway. This gave the desired distance headway as a function of speed. This relation was approximated by a second order polynomial equation to estimate the constant factors of Equation 8.2. To this end, the distance headway was calculated for several values of speed (see Figure 8.7). The intercept of the polynomial equation was set at 3 corresponding to the first constant factor that indicates the minimum distance headway at standstill.

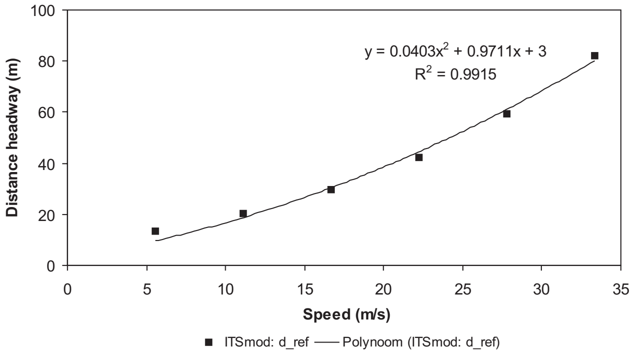


Figure 8.7: Distance headway-speed relation for lane 4 (right) used to estimate c_2 and c_3

Using the approach above, the constant factors for lanes 1 (left) to 4 (right) were estimated. The desired distance headway was calculated using an average vehicle length of 5 m on lanes 1 to 3 and 6.8 m on lane 4. This latter vehicle length is based on 7% heavy trucks in the total traffic demand, corresponding to 30% on lane 4, which results in an average vehicle length of 0.3 * 11 (truck length) + 0.7 * 5 (car length) = 6.8 m. The values for lane 1 differed significantly from those for lanes 2 to 4. This is probably due to the low flows on lane 1 during calm periods in which no real car-following situations took place. Since lane 4 contains most trucks, this lane was used for the constant factors related to trucks. Lanes 2 and 3 were used to estimate those factors for passenger cars. The following equations were used to describe the desired distance headway for cars and trucks respectively:

$$d_{ref} = 3 + 0.8 \cdot v + 0.03 \cdot v^2 \text{ (car)} \tag{8.10}$$

$$d_{ref} = 3 + 1.0 \cdot v + 0.04 \cdot v^2 \text{ (truck)} \tag{8.11}$$

Compared to the default settings, the driver now tries to maintain a larger distance headway. This particularly agrees with congested traffic conditions in which drivers tend to keep much larger distance headways than in non-congested conditions (Dijker et al., 1998). As expected, test runs in the ITS Modeller with the new equations resulted in congestion upstream of the lane drop. However, this congestion dissipated much earlier than on the A12 motorway. Moreover, the traffic flow did not fully recover downstream of the lane drop according to the rather low observed speeds. Therefore, the calibration further concentrated on Equation 8.3 that describes the desired acceleration for car-following:

$$a_{ref\_d} = c_d \cdot \left(d\left(t - t_r\right) - d_{ref}\right) + c_{v\_p} \cdot v_{rel\_p}\left(t - t_r\right) + c_{v\_pp} \cdot v_{rel\_pp}\left(t - t_r\right) \tag{8.3}$$

It was expected that particularly a higher value of the constant factor for the distance deviation would increase the upstream congestion build-up and the downstream recovery from this congestion. Increasing this value would lead to a more fierce reaction of drivers towards deviations from their desired distance headway. Test runs with several different values were performed using 10 replications per run (see also Section 8.3.5). Comparing the speed and flow data from the A12 and the ITS Modeller, it appears that the higher this value, the better the resemblance with respect to the downstream recovery from the congestion in terms of speed. However, the resemblance with respect to the other aspects decreases for a higher value. This is also reflected by the mean squared error (MSE) that was used to define the difference between the actual observations (i.e. A12 data) and the model predictions (i.e. ITS Modeller data). Based on these results, the most appropriate value of the constant factor for the distance deviation was 0.5 instead of the default value 0.3.

Calibration results

Figure 8.8 presents speed-time and flow-time plots based on 1-minute data from the A12 and the ITS Modeller (10 replications), collected about 700 m upstream and about 1000 m downstream of the lane drop.

The speed and flow data from the ITS Modeller resemble those from the A12. In both situations, the congestion due to the lane drop sets in at a similar time (i.e. around 15:50 h) and in a similar way (i.e. ‘sudden’ speed drop). The flow recovers less after the lane drop in the simulation runs, reflected by lower downstream speeds compared to those observed on the A12. Both the empirical and modelled flows follow the same patterns in time, upstream as well as downstream of the lane drop. However, a difference is that the A12 data shows more variation than the ITS Modeller data. This is partly due to the underlying driving behaviour models of the ITS Modeller and it is also caused by averaging the modelling results of 10 replications.

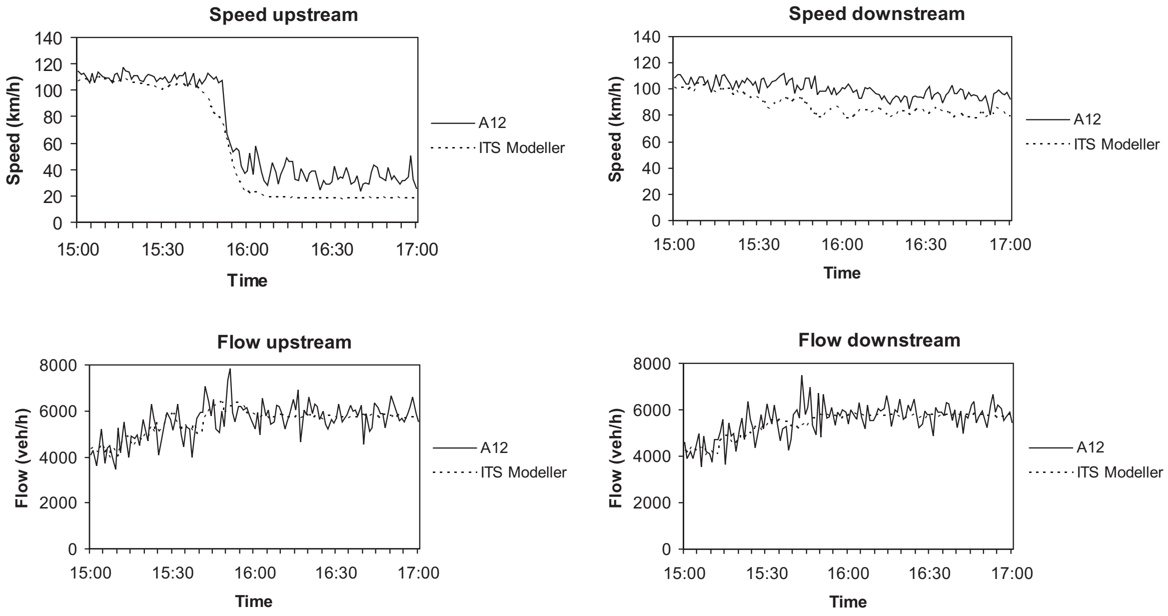


Figure 8.8: Speed-time and flow-time relations based on data from A12 and ITS Modeller

Figure 8.9 presents speed-flow plots based on 5-minute data from the A12 and the ITS Modeller (10 replications), collected about 700 m upstream and about 1000 m downstream of the lane drop.

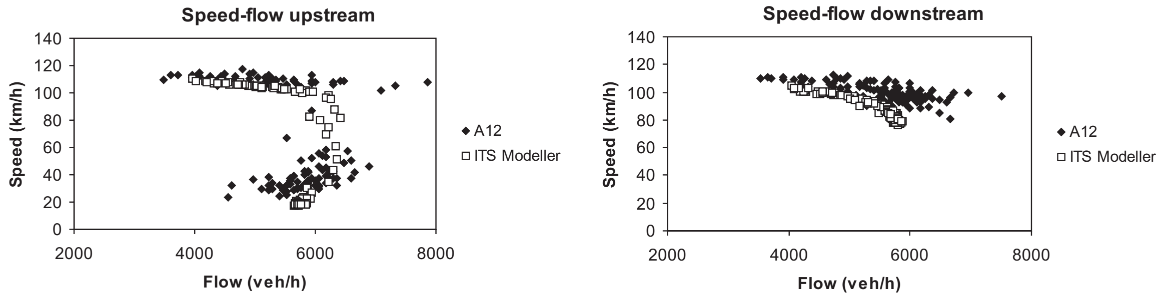


Figure 8.9: Speed-flow relations based on data from A12 and ITS Modeller

The upstream and downstream speed-flow relations found in the ITS Modeller come close to the ones observed in reality on the A12. At the upstream detector, it can be seen that in both situations the traffic was first free flowing, whereas after a while congestion occurred so that the speeds and flows dropped. It can be seen that the free flowing branch of the A12 data has a few measurement points at higher flows than those in the congestion branch. These high flows occurred during a short period of time after which congestion set in. The ITS Modeller data did not include such high flows. Downstream of the lane drop, no congestion occurred and unobstructed flows could be observed. Here the modelled flows and speeds are somewhat smaller compared to the A12 data. Generally, the ITS Modeller data are less scattered than the A12 data.

The following tables show a general overview of the flows and speeds per lane (lane 1 is the left lane), about 700 m upstream (Table 8.3) and about 1000 m downstream of the lane drop (Table 8.4). ‘Ref’ stands for the reference situation simulated by the ITS Modeller.

Table 8.3: Upstream speeds and flows: empirical versus modelling data

	Flow upstream (veh/h)					**Speed upstream (km/h)**				
	Total	*Lane 1*	*Lane 2*	*Lane 3*	*Lane 4*	*Average*	*Lane 1*	*Lane 2*	*Lane 3*	*Lane 4*
A12	5574	17%	32%	31%	20%	68.6	79.1	69.8	66	59.7
Ref	5528	23%	26%	27%	24%	55.9	60.5	57.7	55.9	50.4

Table 8.4: Downstream speeds and flows: empirical versus modelling data

	Flow downstream (veh/h)				**Speed downstream (km/h)**			
	Total	*Lane 1*	*Lane 2*	*Lane 3*	*Average*	*Lane 1*	*Lane 2*	*Lane 3*
A12	5543	40%	39%	21%	99.9	108.3	103.1	88.1
Ref	5433	33%	34%	33%	87.2	99.4	87.1	75.4

Both the upstream and downstream total flows of the ITS Modeller are close to the total flows of the A12. It can be seen that the division of the flow among the lanes is distributed more evenly in the ITS Modeller compared to reality. Generally, the speeds of the ITS Modeller are lower than the speeds of the A12. However, the differences between the speeds per lane are realistic, that is the speeds on a left lane are higher than on a right lane.

In summary, the ITS Modeller was calibrated focusing on the onset of congestion (i.e. time and location). Parameters of the driver model were therefore optimized in a systematic and transparent way. It can be concluded that the calibration of the ITS Modeller has resulted in satisfactory outcomes with respect to the congestion build-up. The modelling results were found to be in reasonable agreement with real traffic measured on the Dutch A12 motorway near a left lane drop from 4 to 3 lanes. The congested conditions caused by this lane drop are represented well in the simulation runs, both upstream and downstream of the lane drop. Further calibration and modelling efforts could lead to a more detailed resemblance of the model to reality. However, the current version of the ITS Modeller was considered adequate to study the traffic flow impacts of the Congestion Assistant.

Validation results

The reference situation was validated using measured loop data measured between 15:01-17:00 h on the same segment of the Dutch A12 motorway near Woerden. Now data gathered on another day, namely Wednesday 10 May 2006, were used. Figure 8.10 shows speed-time and flow-time plots based on 1-minute data from the A12 and the ITS Modeller (10 replications), collected about 700 m upstream and about 1000 m downstream of the lane drop. Figure 8.11 presents speed-flow plots based on 5-minute data from the A12 and the ITS Modeller (10 replications), collected about 700 m upstream and about 1000 m downstream of the lane drop. Based on these figures, it was concluded that the outcomes of the ITS Modeller correspond well with the traffic flow characteristics observed on the A12 near the lane drop.

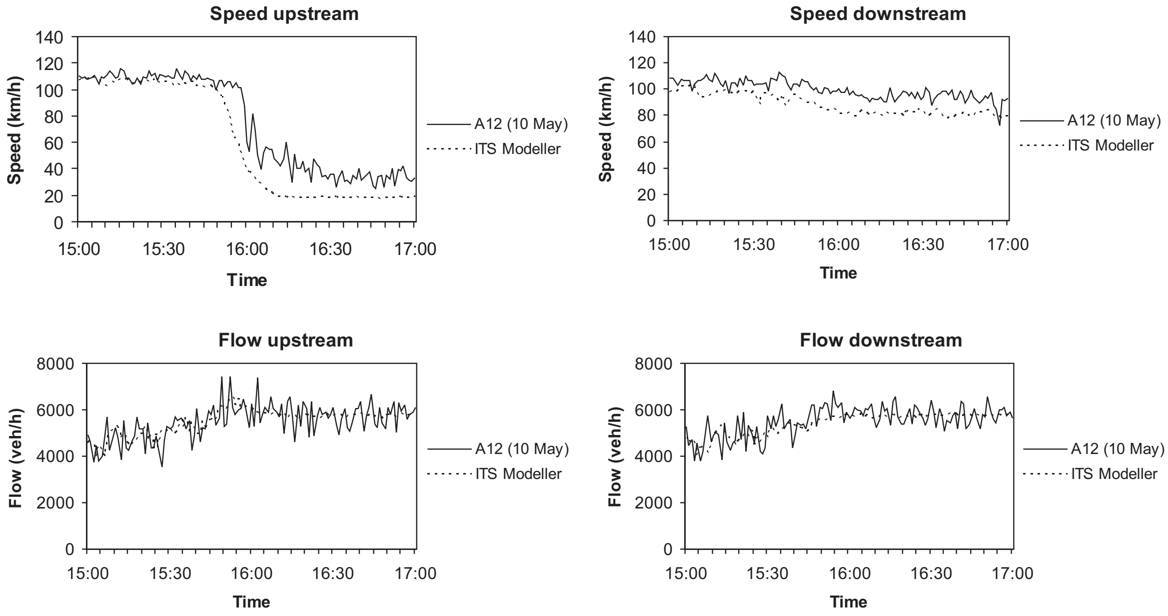


Figure 8.10: Speed-time and flow-time relations based on data from A12 (10 May 2006) and ITS Modeller

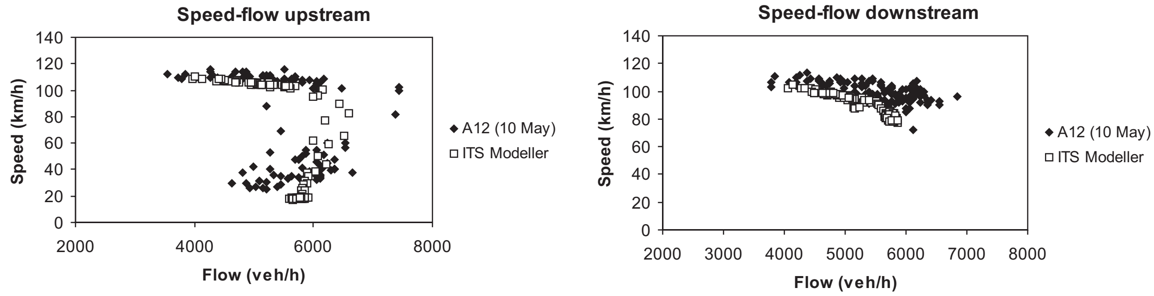


Figure 8.11: Speed-flow relations based on data from A12 (10 May 2006) and ITS Modeller

8.3.5 Data collection and analysis

Simulation

In total thirteen scenarios were studied in the ITS Modeller, including twelve experimental scenarios (i.e. six variants of the Congestion Assistant at two equipment rates) and the reference situation. The simulation duration of each scenario was set at 2.5 hours. After about one hour, congestion set in upstream of the lane drop. The first and last 15 minutes of the simulation runs were not taken into account in the analyses because of possibly irregular traffic behaviour at the beginning and the end of the simulated road.

The ITS Modeller aims at simulating the complex behaviour of traffic flows in which randomness is involved. Each run therefore provides one possible result of this behaviour. The final result is obtained by processing a number of replications per scenario using different random seeds. The method described by Law & Kelton (2000) was used to calculate the number of replications. This method provides the number of replications required to obtain an estimate of the sample mean μ with a relative error of γ ($0<\gamma<1$) and a confidence level of

100(1-α) percent ($0<\alpha<1$). It appeared that ten replications per scenario would lead to values of the upstream speed within the limits of 10% of the sample mean with a 95% level of confidence. It was decided that ten replications per scenario was a good compromise between valid estimates of the behaviour at the one hand and the available time budget on the other.

Indicators and analyses

Several measures were selected to study the impacts of the Congestion Assistant on traffic efficiency and traffic safety, and to answer the hypotheses mentioned in Section 8.1. The following measures of traffic efficiency were taken into account: speed and queue discharge flow. The speed was measured at each detector of the network and aggregated to 1-minute values. The data were used for speed-time plots at the upstream detector to study changes in the amount of congestion observed at 750 m before the lane drop. The data were also used for plots that display speed as a function of time and location to examine the onset and the course of congestion on the whole network. The queue discharge flow was calculated by averaging the three highest 5-minute traffic flows at the downstream detector as long as the upstream congestion was present. This means that only flows measured after one hour from the start (including the first 15 minutes of the run) were taken into account.

The following measures of traffic safety were collected: speed variation in terms of standard deviation of speed, percentage of hard braking and percentage of small Time-To-Collision (TTC) values. The standard deviation of speed was based on the individual speed measurements on the whole network (collected each 0.1 s) and aggregated to a network value. The percentage of hard braking consisted of the percentage of vehicles that had a deceleration smaller than -3.5 m/s^2. The percentage of small TTCs was expressed by the percentage of vehicles that had a TTC value smaller than 4 s. Both the percentage of hard braking and the percentage of small TTCs were based on the individual measurements on the whole network (collected at 0.1 s) and aggregated to a network value. The data were used for plots that display the network values of the indicators to study differences between the scenarios. These differences were also statistically analysed by performing paired-sample T tests. When $p<0.05$, the results were considered to be statistically significant, which indicated that the scenarios differed from each other. The paired-sample T test is appropriate when two related sample means are to be compared and when the difference scores follow a normal distribution. In our case, the scenarios were related to each other, because the same random seeds were applied for the ten runs per scenario. Before running the T tests, the distribution of the difference scores were assessed by examining histograms and performing Kolmogorov-Smirnov tests. All difference scores revealed to follow a normal distribution ($p<0.05$).

8.4 Results

8.4.1 Traffic efficiency

Six variants of the Congestion Assistant consisting of the Active pedal and/or the Stop & Go were studied at 10% and 50% equipment rates. First, the impacts of the four variants of the Congestion Assistant with only the Active pedal or the Stop & Go (i.e. the 'single' variants) on traffic efficiency are presented. Next, the focus lies on the results of the two variants with a combination of the Active pedal and the Stop & Go (i.e. the 'combined' variants). After that, the contributions of the two driver support functions to the results of the combined variants are given. Table 8.5 explains the notation used for the variants of the Congestion Assistant.

Table 8.5: Notation of variants of Congestion Assistant

Notation	Functions of Congestion Assistant
1500 m 500 m	Active pedal working from 1500 m or 500 m before jam
1.0 s 0.8 s	Stop & Go with time headway of 1.0 s or 0.8 s
1500 m & 1.0 s 500 m & 0.8 s	Active pedal working from 1500 m or 500 m before jam and Stop & Go with time headway of 1.0 s or 0.8 s

Congestion Assistant: Active pedal or Stop & Go

The results of the variants of the Congestion Assistant consisting of either the Active pedal or the Stop & Go are presented below. Figure 8.12 shows the speed-time plots based on 1-minute data collected at the upstream detector. The upper part displays the scenarios with 10% of the vehicles equipped with the Congestion Assistant, while the lower part displays a 50% equipment rate.

Particularly the Stop & Go variants of the Congestion Assistant resulted in a much higher upstream speed compared to the reference situation. Note that the Stop & Go was active further downstream, which affected the traffic situation at the upstream detector. Less congestion was observed at the upstream detector when 10% of the vehicles were equipped with these variants. The congestion even disappeared when 50% of the vehicles were equipped, regardless of the time headway setting. The Active pedal variants of the Congestion Assistant had less influence on the upstream speed. However, with an equipment rate of 50%, these variants showed an improvement with respect to the reference situation, regardless of the distance setting. It can be also seen that the Active pedal variants led to a more gradual speed drop when congestion set in compared to the other variants and the reference situation.

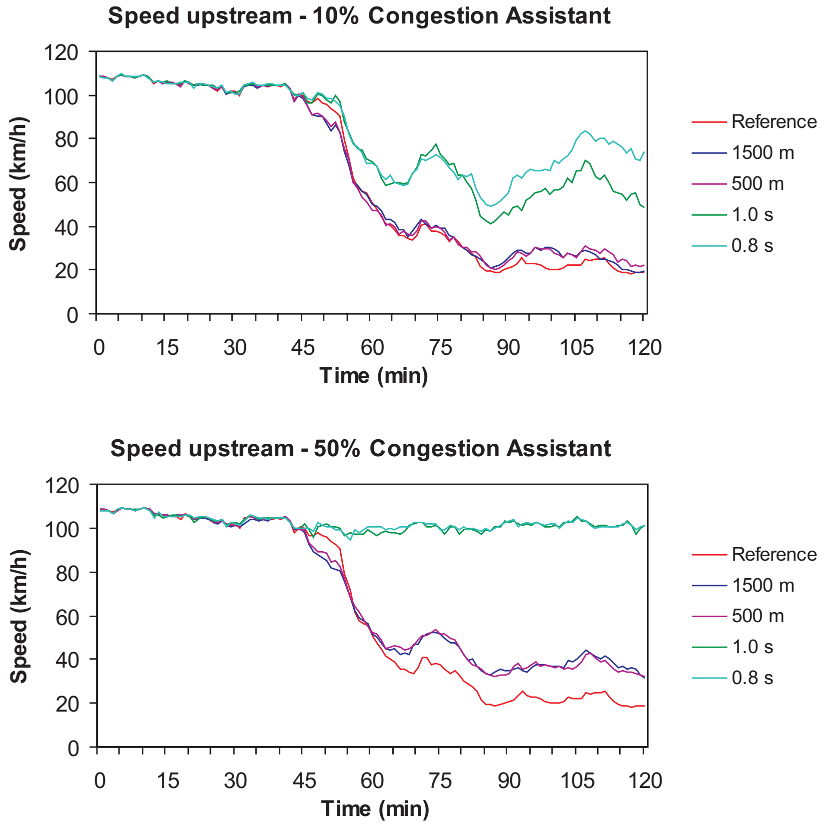
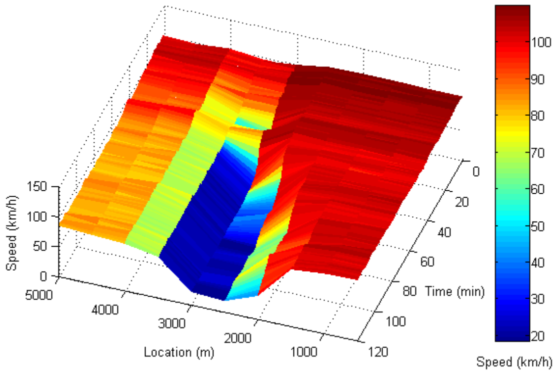


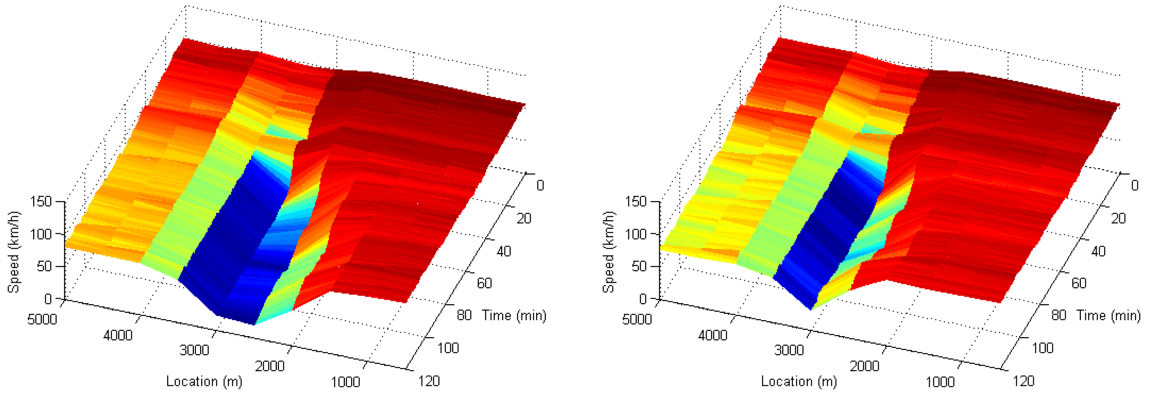
Figure 8.12: Speed-time relations upstream of lane drop: reference versus single variants of Congestion Assistant (10% and 50%)

The impacts of the Congestion Assistant on the onset and the course of congestion can be illustrated by the plots in Figure 8.13 that show the average speed as a function of time and location. These plots are based on 1-minute data collected at ten detectors located 500 m apart from each other on the simulated motorway segment. The lane drop from 4 to 3 lanes is situated around 3250 m. The plots show the average speed in time and location for the reference situation and for two variants of the Congestion Assistant consisting of an Active pedal working from 1500 m before the jam or a Stop & Go with a time headway of 0.8 s. The plots of the other two single variants of the Congestion Assistant look similar to their ‘counterparts’.

The onset of congestion in the scenarios with the Congestion Assistant started at a similar time and location as in the reference situation. However, the amount of congestion was reduced in these scenarios, especially when the Congestion Assistant consisted of the Stop & Go. This means that the origin of congestion stays the same (i.e. the lane drop), but the development of it changes. Due to the Congestion Assistant, the traffic jam hardly grows at the queue tail, while at the same time traffic at the queue head quickly leaves the congested regime. Compared to intervening in approaching a jam (i.e. Active pedal), intervening in driving in a jam (i.e. Stop & Go) obtains the greatest improvement in traffic efficiency. However, it can also be seen that the Stop & Go variant led to lower speeds downstream of the lane drop compared to the Active pedal variant and the reference situation. The effects of the system on the amount of congestion and the downstream speed were larger when more vehicles were equipped with the Congestion Assistant, regardless of its variant.

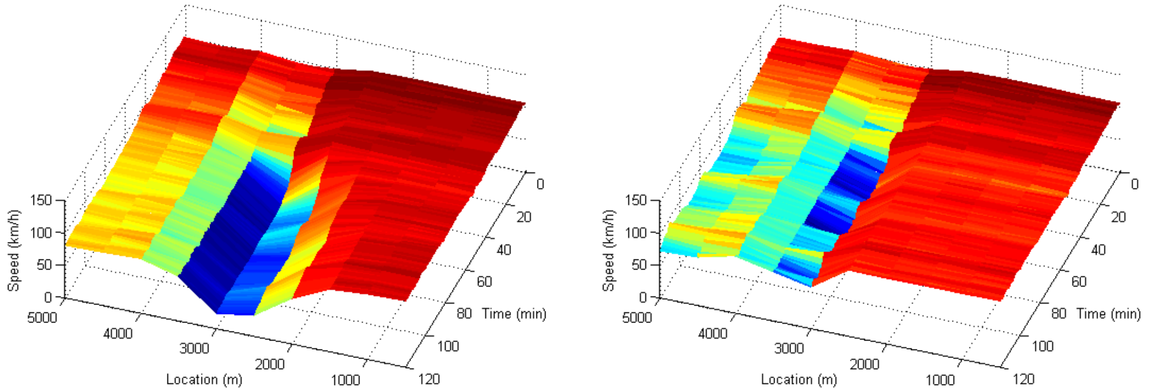


a) Reference



b) 1500 m (10%)

c) 0.8 s (10%)



d) 1500 m (50%)

e) 0.8 s (50%)

Figure 8.13: Speed in time and location: reference versus two single variants of Congestion Assistant (10% and 50%)

Figure 8.14 shows the queue discharge flow in the reference situation and in the situations with the Congestion Assistant. It can be seen that the four single variants of the Congestion Assistant resulted in a higher queue discharge flow (i.e. congestion outflow) compared to the reference situation. The outflows in the scenarios with 50% equipment rate of the Congestion Assistant were higher than the ones with 10% equipment rate. The Stop & Go variants showed much higher outflows than the Active pedal variants. Comparing the 10% equipment rate scenarios with the reference situation, the Active pedal variants led to an outflow improvement of up to 0.4%, while the Stop & Go variants led to an improvement of up to 2.8%. The highest outflow was obtained when 50% of the vehicles were equipped with a Congestion Assistant consisting of a Stop & Go with a time headway of 0.8 s. This outflow was 7.0% higher than the one observed in the reference situation.

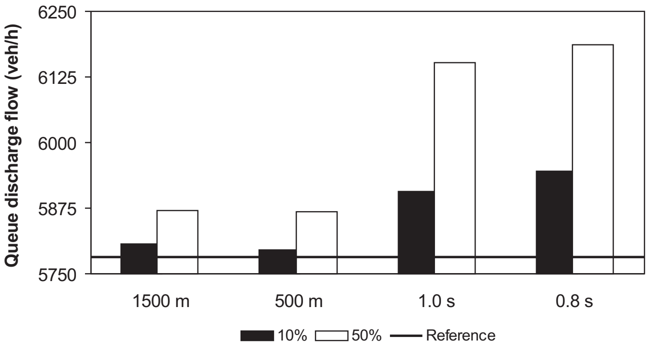


Figure 8.14: Queue discharge flows: reference versus single variants of Congestion Assistant (10% and 50%)

The higher outflows with the Congestion Assistant can especially be attributed to the Stop & Go. This system leads to more efficient car-following behaviour when driving in and leaving a jam by maintaining smaller headways and eliminating the reaction time of drivers. Besides, the smaller time headway that drivers maintain after having driven with the Stop & Go has a positive effect on the congestion outflow.

Congestion Assistant: Active pedal and Stop & Go

The results of the variants of the Congestion Assistant consisting of a combination of the Active pedal and the Stop & Go are presented below. Figure 8.15 (on page 135) shows the speed-time plots based on 1-minute data collected at the upstream detector located 750 m upstream of the lane drop. The upper part displays the scenarios with 10% of the vehicles equipped with the Congestion Assistant, while the lower part displays a 50% equipment rate.

These two combined variants of the Congestion Assistant resulted in a much higher upstream speed compared to the reference situation. Less congestion was observed at the upstream detector when 10% of the vehicles were equipped with the Congestion Assistant. The congestion even disappeared when 50% of the vehicles were equipped with the system. Both in the 10% and 50% equipment rate scenarios, a Congestion Assistant consisting of an Active pedal working from 500 m before the jam and a Stop & Go with a time headway of 0.8 s showed the greatest improvement.

The impacts of the combined variants of the Congestion Assistant on the onset and the course of congestion can be illustrated by the plots in Figure 8.16 that show the average speed as a function of time and location. Both variants of the Congestion Assistant show that the onset of congestion started at a similar time and location as in the reference situation. However, the amount of congestion was reduced significantly in the scenarios with the system. Yet the speeds downstream of the lane drop were lower in the situations with the Congestion Assistant compared to the reference situation. All results are even clearer when 50% of the vehicles were equipped with the system compared to an equipment rate of 10%. The variant including an Active pedal working from 500 m before the jam and a Stop & Go with a time headway of 0.8 s showed less congestion, but also lower downstream speeds than the other combined variant.

Figure 8.17 shows the queue discharge flow in the reference situation and in the situations with the Congestion Assistant. It can be seen that the two combined variants of the Congestion Assistant resulted in a higher queue discharge flow (i.e. congestion outflow) compared to the reference situation. The variants led to an outflow improvement of up to 2.8% when 10% of the vehicles were equipped with the system, while an improvement of up to 7.3% was obtained with an equipment rate of 50%. This highest outflow was obtained when the Congestion Assistant consisted of an Active pedal working from 500 m before the jam and a Stop & Go with a time headway of 0.8 s.

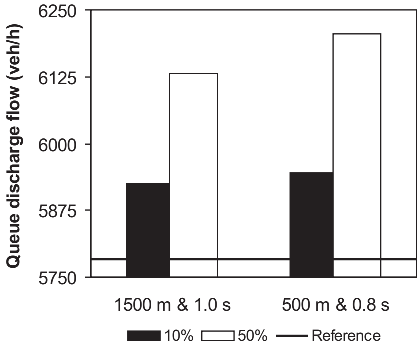
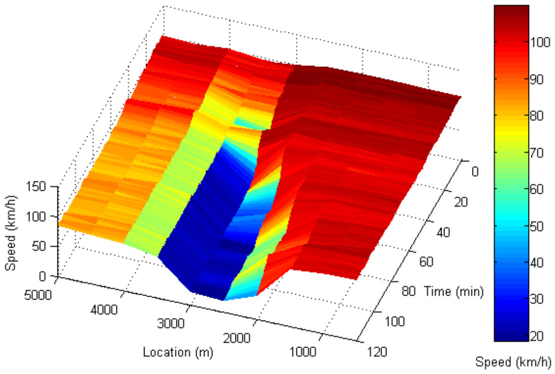
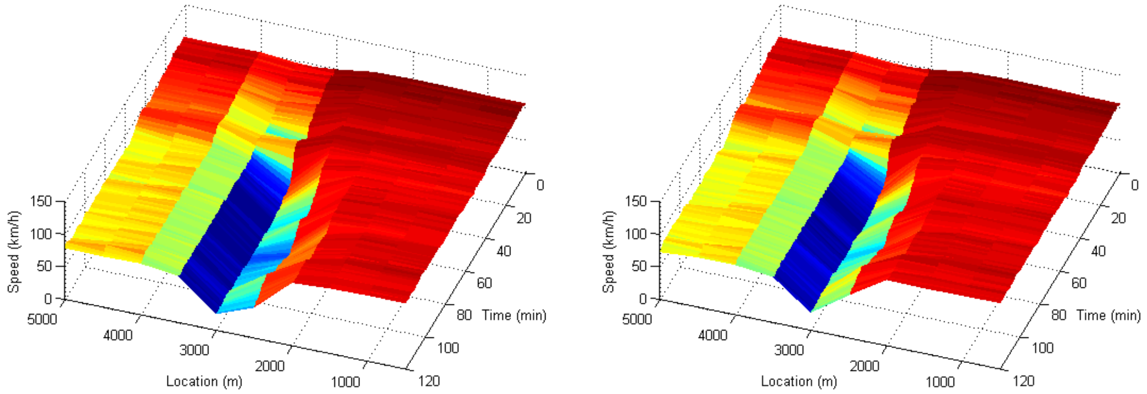


Figure 8.17: Queue discharge flows: reference versus combined variants of Congestion Assistant (10% and 50%)

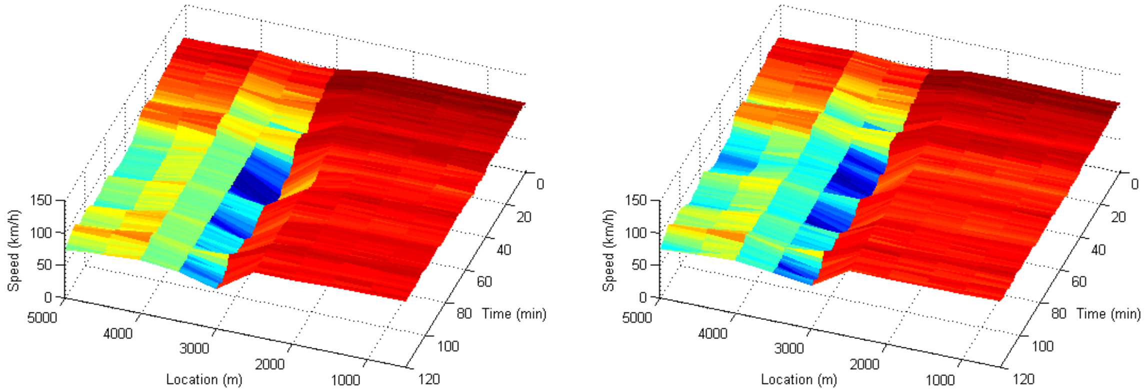


a) Reference



b) 1500 m & 1.0 s (10%)

c) 500 m & 0.8 s (10%)



d) 1500 m & 1.0 s (50%)

e) 500 m & 0.8 s (50%)

Figure 8.16: Speed in time and location: reference versus combined variants of Congestion Assistant (10% and 50%)

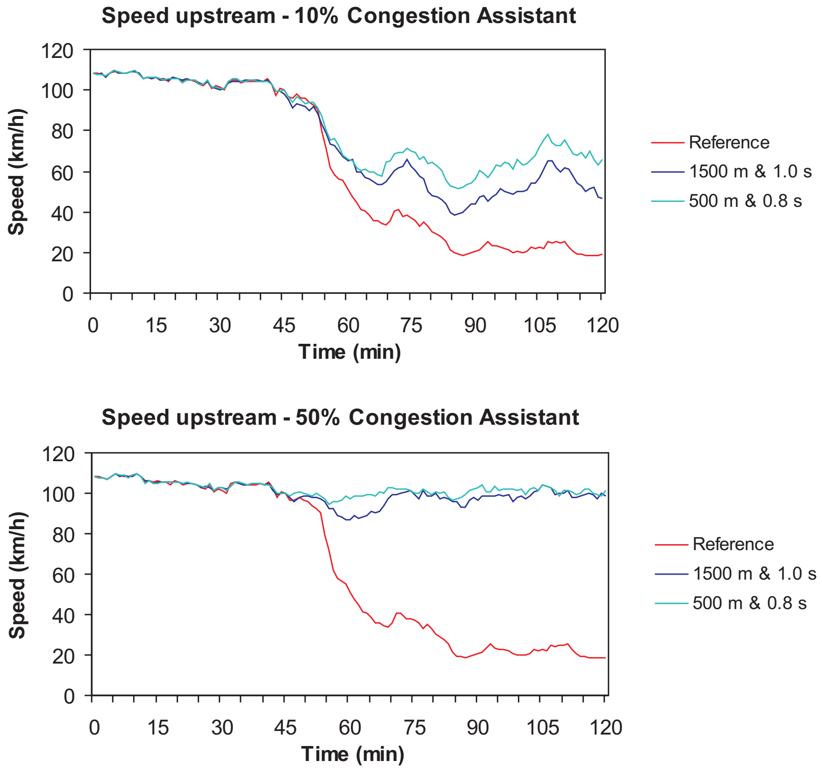


Figure 8.15: Speed-time relations upstream of lane drop: reference versus combined variants of Congestion Assistant (10% and 50%)

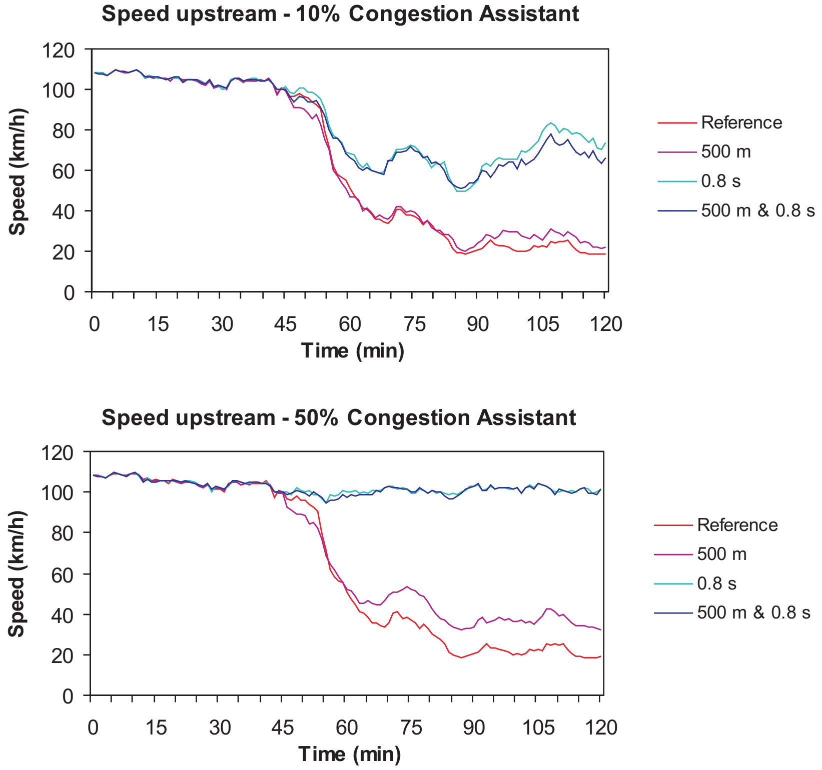


Figure 8.18: Speed-time relations upstream of lane drop: reference and single versus combined variants of Congestion Assistant (10% and 50%)

Contributions of Active pedal and Stop & Go

Comparing the findings of the two sections above shows the contributions of the Active pedal and the Stop & Go to the efficiency results of the Congestion Assistant consisting of a combination of these functions. All variants resulted in less congestion than the reference situation. However, these positive effects were much larger due to the Stop & Go variants and the combined variants compared to the Active pedal variants. In fact, the results of the Stop & Go variants and the combined variants were very similar. This means that the Active pedal in the combined variants has no added value with respect to traffic efficiency. This observation applied to both the speed data and the queue discharge flow data. Figure 8.18 (on page 135) presents the speed-time plots of one combined variant of the Congestion Assistant and the two related single variants based on 1-minute data collected at the upstream detector. It illustrates that the combined variant did not necessarily lead to better results than the variants with either an Active pedal or a Stop & Go.

8.4.2 Traffic safety

First, the impacts of the four variants of the Congestion Assistant with only the Active pedal or the Stop & Go (i.e. the ‘single’ variants) on traffic safety are presented. Next, the focus lies on the results of the two variants with a combination of the Active pedal and the Stop & Go (i.e. the ‘combined’ variants). After that, the contributions of the two driver support functions to the results of the combined variants are given.

Congestion Assistant: Active pedal or Stop & Go

Figure 8.19 shows the standard deviation of speed on the whole network in the reference situation and in the situations with the Congestion Assistant. The four single variants of the Congestion Assistant led to significantly smaller standard deviations of speed compared to the reference situation. The speed variation in the scenarios with 50% equipment rate of the Congestion Assistant was significantly less than with 10% equipment rate. The Stop & Go variants resulted in much smaller standard deviations of speed than the Active pedal variants. No differences in speed variation were found between the Active pedal settings. The standard deviations of speed were smallest when 50% of the vehicles were equipped with a Congestion Assistant consisting of a Stop & Go with a time headway of 0.8 s. In this scenario, the congestion almost disappeared due to the Congestion Assistant, which resulted in little speed variation, indicating a stable and homogeneous flow.

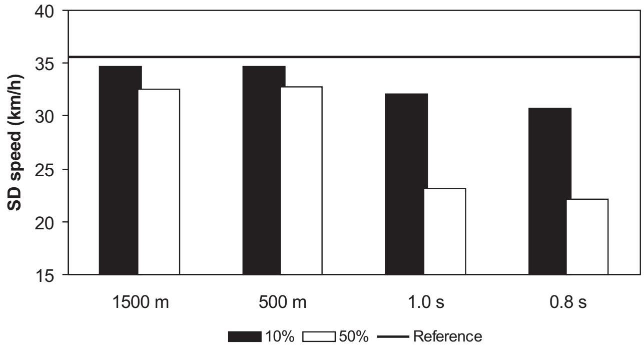


Figure 8.19: Standard deviation of speed on network: reference versus single variants of Congestion Assistant (10% and 50%)

Figure 8.20 shows the percentage of hard braking (<-3.5 m/s^2) on the whole network in the reference situation and in the situations with the single variants of the Congestion Assistant. Statistical results showed that particularly the Stop & Go variants led to significantly more hard braking actions compared to the reference situation. In these scenarios, the percentages of hard braking with 10% equipment rate were significantly lower than the ones with 50% equipment rate. The highest percentage of hard braking was obtained when 50% of the vehicles were equipped with the 0.8s-variant. Detailed analyses revealed that these hard braking actions mainly occurred just before the lane drop, in the traffic jam. The amount of hard braking can be attributed to both vehicles with and without the Stop & Go. This seems obvious as they react to each other. Presumably, the Stop & Go causes the hard braking actions as a result of its small time headway in combination with the merging process. It is expected that merging vehicles use smaller gaps (created by the Stop & Go vehicles) than desired, so that they will brake after the cut-in manoeuvre to increase their headway again. The Active pedal variants resulted in a similar level of hard braking as the reference situation, except when 50% of the vehicles were equipped, regardless of the distance setting. These scenarios led to the lowest percentages of hard braking, because the Active pedal likely caused vehicles (including non-equipped vehicles) to better anticipate the traffic jam by earlier and calmer decelerations.

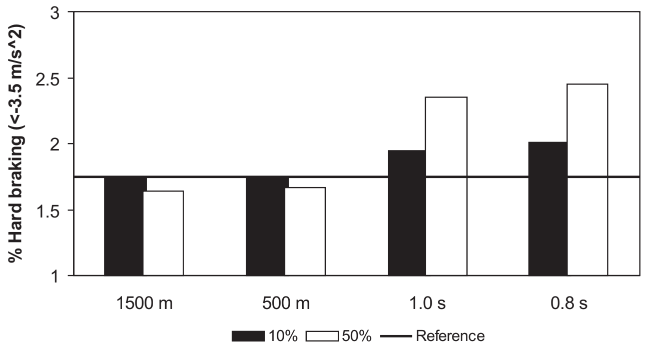


Figure 8.20: Percentage of hard braking (<-3.5 m/s^2) on network: reference versus single variants of Congestion Assistant (10% and 50%)

Figure 8.21 shows the percentage of TTC <4 s on the whole network in the reference situation and in the situations with the single variants of the Congestion Assistant.

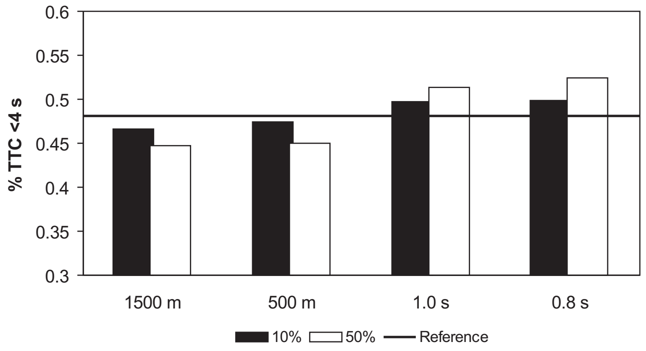


Figure 8.21: Percentage of TTC <4 s on network: reference versus single variants of Congestion Assistant (10% and 50%)

Statistical results showed that these variants of the Congestion Assistant led to some differences in the occurrence of potentially unsafe following situations compared to the reference situation. The Active pedal variants resulted in smaller percentages of TTC <4 s than the reference situation, indicating less unsafe following situations, except when 10% of the vehicles were equipped with the 500m-variant. Detailed analyses revealed that particularly before the lane drop, when approaching and driving in the traffic jam, the following situations were safer due to the Active pedal. On the contrary, the Stop & Go variants led to higher percentages of TTC <4 s than the reference situation, regardless of the time headway setting and the equipment rate. Detailed analyses showed that these percentages were mainly found just before the lane drop, in the traffic jam.

Congestion Assistant: Active pedal and Stop & Go

The results of the variants of the Congestion Assistant consisting of a combination of the Active pedal and the Stop & Go are presented below. Figure 8.22 presents the standard deviation of speed on the whole network in the reference situation and in the situations with the Congestion Assistant. The two combined variants of the Congestion Assistant led to significantly smaller standard deviations of speed compared to the reference situation. The speed variation in the scenarios with 50% equipment rate of the Congestion Assistant was significantly less than with 10% equipment rate. In these scenarios, the congestion almost disappeared due to the Congestion Assistant, which resulted in little speed variation. The standard deviations of speed were smallest when 50% of the vehicles were equipped with the Congestion Assistant consisting of an Active pedal working from 500 m before the jam and a Stop & Go with a time headway of 0.8 s.

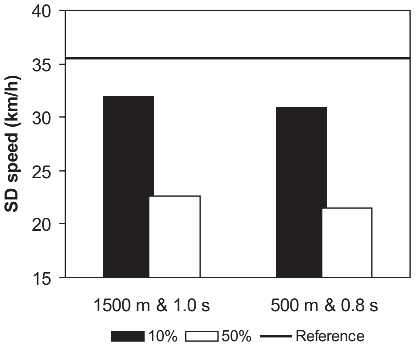


Figure 8.22: Standard deviation of speed on network: reference versus combined variants of Congestion Assistant (10% and 50%)

Figure 8.23 shows (a) the percentage of hard braking (<-3.5 m/s^2) and (b) the percentage of TTC <4 s on the whole network in the reference situation and in the situations with the combined variants of the Congestion Assistant.

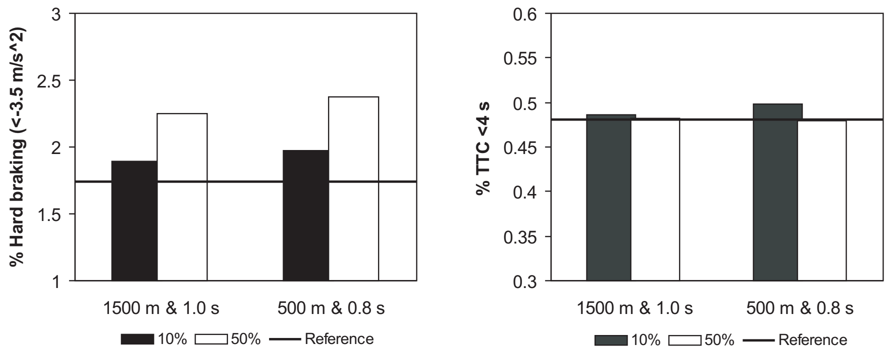


Figure 8.23: (a) Percentage of hard braking (<-3.5 m/s^2) and (b) Percentage of TTC <4 s on network: reference versus combined variants of Congestion Assistant (10% and 50%)

Statistical results showed that these variants of the Congestion Assistant led to significantly more hard braking actions compared to the reference situation. The percentages of hard braking in the scenarios with 10% equipment rate of the Congestion Assistant were significantly lower than the ones with 50% equipment rate. The highest percentage of hard braking was obtained when 50% of the vehicles were equipped with the Congestion Assistant consisting of an Active pedal working from 500 m before the jam and a Stop & Go with a time headway of 0.8 s. The lowest percentage of hard braking was obtained when 10% of the vehicles were equipped with a combination of the 1500m-variant of the Active pedal and the 1.0s-variant of the Stop & Go.

The combined variants of the Congestion Assistant showed no differences in the occurrence of potentially unsafe following situations compared to the reference situation, except for one scenario. When the equipment rate was 10%, the Congestion Assistant consisting of an Active pedal working from 500 m before the jam and a Stop & Go with a time headway of 0.8 s resulted in a larger percentage of TTC <4 s, indicating more unsafe following situations than the reference situation.

Contributions of Active pedal and Stop & Go

Comparing the findings of the two sections above shows the contributions of the Active pedal and the Stop & Go to the safety results of the Congestion Assistant consisting of a combination of these functions. It appeared that the combined variants of the Congestion Assistant did not necessarily lead to better results than the variants with either an Active pedal or a Stop & Go. Including the Stop & Go in the Congestion Assistant resulted in large positive effects on the standard deviation of speed, but it also led to large negative effects on the occurrence of hard braking situations. The Active pedal did not add to larger positive effects on speed variation compared to a Congestion Assistant with only a Stop & Go. On the other hand, adding an Active pedal to the Stop & Go decreased the percentages of hard braking and small TTCs, particularly at a 50% equipment rate (see Figure 8.24). However, it did not lead to larger positive effects on these percentages compared to a Congestion Assistant consisting of only an Active pedal.

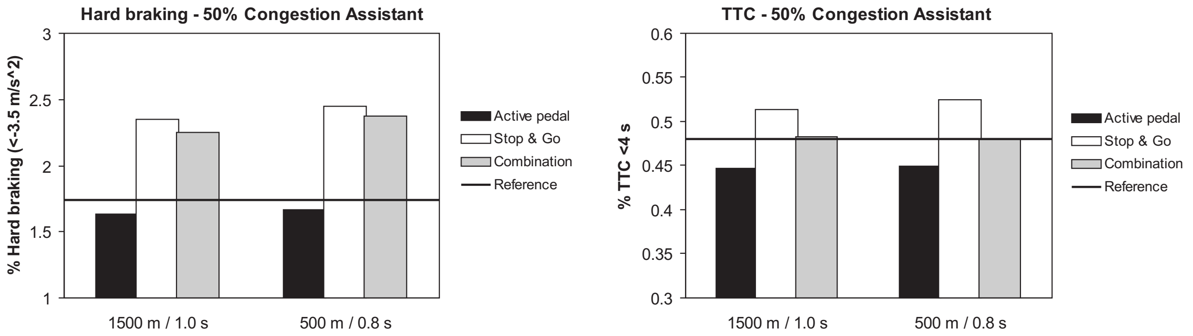


Figure 8.24: (a) Percentage of hard braking (<-3.5 m/s^2) and (b) Percentage of TTC <4 s on whole network: reference and single versus combined variants of Congestion Assistant (50%)

8.5 Discussion

8.5.1 Overview of results

The impacts of six variants of the Congestion Assistant on motorway traffic were studied by means of a microscopic traffic simulation study. The variants concerned a Congestion Assistant consisting of an Active pedal, a Stop & Go or a combination of both functions. In the scenarios with the Congestion Assistant, 10% or 50% of the vehicles were equipped with the system. This section discusses the results on traffic efficiency and traffic safety. The hypotheses mentioned in Section 8.1 serve as a guideline for presenting these results.

Traffic efficiency

In all scenarios, the left lane drop from 4 to 3 lanes caused congestion. All variants of the Congestion Assistant resulted in less congestion compared to the reference situation, especially when the system included the Stop & Go. The Active pedal caused a reduction in the amount of congestion by intervening in approaching a jam, this way reducing the congestion inflow. However, a much bigger reduction in the amount of congestion was obtained by the Stop & Go. This function intervened in driving in a jam and showed a more efficient car-following behaviour. Concerning the queue discharge flow, all variants of the Congestion Assistant led to higher congestion outflows compared to the reference situation. The Stop & Go variants showed higher outflows than the Active pedal variants, although combined with lower downstream speeds. These higher outflows can be attributed to the efficient driving behaviour of the Stop & Go and the closer following behaviour of drivers after they have driven with the Stop & Go. Thus, as expected, both the Active pedal and the Stop & Go have positive effects on the dissipation of jams, but the effects due to the Stop & Go are much larger. This corresponds to the literature stating that particularly ACC systems, such as the Stop & Go, can outperform manual traffic and compensate for unfavourable human behaviour (Zwaneveld & Van Arem, 1997; Treiber et al., 2006).

The two variants of the Active pedal (i.e. working from 1500 m respectively 500 m before the jam) hardly showed any differences. However, the two variants of the Stop & Go (i.e. with a time headway of 1.0 s respectively 0.8 s) showed more differences. The 0.8s-variant led to somewhat less congestion than the 1.0s-variant, although the latter variant resulted in a higher speed downstream of the lane drop. Nonetheless, a higher queue discharge flow was found with the 0.8s-variant compared to the 1.0s-variant, regardless of the equipment rate. Generally, the Stop & Go with a time headway of 0.8 s produces larger positive effects on traffic efficiency than the variant with a time headway of 1.0 s. This effect of a small time headway on traffic efficiency is in accordance with earlier findings (Minderhoud, 1999; Benz et al., 2003).

The contributions of the Active pedal and the Stop & Go to the results of the Congestion Assistant consisting of a combination of both functions were studied. It was expected that combining the Active pedal and the Stop & Go would result in the largest effects on traffic efficiency. However, the combined variants of the Congestion Assistant were not found to necessarily lead to other (i.e. better) results than the variants with either an Active pedal or a Stop & Go. Although all variants caused less congestion, these effects were much larger due to the Stop & Go variants and the combined variants compared to the Active pedal variants. In fact, the results of the Stop & Go variants and the combined variants were very similar. The results of the queue discharge flow showed the same findings. This means that the Active pedal has no added value when it is combined with the Stop & Go. Thus, a Congestion Assistant consisting of a combination of an Active pedal and a Stop & Go does not lead to larger positive effects on traffic efficiency compared to one consisting of only a Stop & Go.

Furthermore, it was expected that a higher penetration rate of the Congestion Assistant would lead to larger effects on the dissipation of jams. Indeed, the results showed that the positive effects on traffic efficiency significantly increased when 50% of the vehicles were equipped with the system compared to an equipment rate of 10%. The expectation that a high penetration rate of the Active pedal could potentially result in new jams due to ‘too early’ braking was not confirmed, regardless of its settings.

Traffic safety

All variants of the Congestion Assistant led to less congestion compared to the reference situation. This is also reflected by the speed variation. The Congestion Assistant resulted in smaller standard deviations of speed than the reference situation, indicating a more stable and homogeneous flow. A reduction in speed variation could be obtained by intervening in approaching a jam (i.e. Active pedal), but also by intervening in driving in a jam (i.e. Stop & Go). However, the impacts of the Stop & Go variants were much larger than those of the Active pedal variants.

With respect to the percentage of hard braking and the percentage of TTC <4 s and a 10% equipment rate, the Active pedal variants had a similar level of safety as the reference situation. An equipment rate of 50% generally led to less hard braking actions and less unsafe following situations than the reference situation, due to a more smooth approach to the traffic jam. However, the Stop & Go variants, especially the 0.8s-variants, led to higher percentages of hard braking. The Stop & Go presumably increases the amount of hard braking by forcing merging vehicles to use a smaller gap (created by the Stop & Go) than desired, after which these vehicles will start braking. The Stop & Go also attributed to the occurrence of small TTCs. This finding is not consistent with earlier research by TRG (2004), which showed a decreased number of small TTCs due to a Stop & Go. However, it should be noted that small TTCs during automatic driving are less dangerous than small TTCs during manual driving, since the automatic system (e.g. the Stop & Go) can outperform the human driver, for example with respect to the reaction time.

The two variants of the Active pedal (i.e. working from 1500 m respectively 500 m before the jam) showed no differences with respect to speed variation, hard braking and TTC. However, the two variants of the Stop & Go (i.e. with a time headway of 1.0 s respectively 0.8 s) did. The 0.8s-variant led to smaller standard deviations of speed than the 1.0s-variant, regardless of the equipment rate. The 0.8s-variant also resulted in more hard braking actions than the 1.0s-variant, but only when 50% of the vehicles were equipped. No differences were found between the percentage of TTC <4 s.

It was expected that both the Active pedal and the Stop & Go would lead to positive effects on traffic safety due to a more stable and homogeneous flow. This can be confirmed based on the speed variation data. For the Active pedal, this is also true based on the TTC data and the hard braking data. However, for the Stop & Go, the TTC data showed no improvement in traffic safety and the hard braking data even indicated a deterioration of traffic safety.

Combining the Active pedal and the Stop & Go was expected to result in the largest effects on traffic safety. But the combined variants of the Congestion Assistant did not necessarily lead to better results than the variants with either an Active pedal or a Stop & Go. Including the Stop & Go in the Congestion Assistant resulted in large positive effects on the standard deviation of speed, but it also led to large negative effects on the occurrence of hard braking situations. The Active pedal did not add to larger positive effects on speed variation compared to a Congestion Assistant with only a Stop & Go. On the other hand, adding an Active pedal to the Stop & Go decreased the percentages of hard braking and small TTCs, although it did not lead to larger positive effects on these percentages compared to a Congestion Assistant consisting of only an Active pedal.

Furthermore, it was expected that a higher penetration rate of the Congestion Assistant would lead to larger effects on traffic safety. The results showed that for all variants the standard deviation of speed significantly decreased when 50% of the vehicles were equipped with the system compared to an equipment rate of 10%. This was also true for the Active pedal variants with respect to the percentage of hard braking and the percentage of small TTCs. However, for the Stop & Go variants, an equipment rate of 50% increased the percentage of hard braking and the percentage of small TTCs compared to an equipment rate of 10%. Thus, a higher equipment rate of the Congestion Assistant particularly increases the positive effects on traffic safety with respect to speed variation. Concerning the Active pedal variants, it also leads to an improvement of traffic safety in terms of less hard braking actions and less unsafe following situations. But a higher equipment rate of the Congestion Assistant consisting of only a Stop & Go might decrease traffic safety, especially due to the higher percentage of hard braking.

8.5.2 Conducting the study

The simulation environment ITS Modeller was used to assess the impacts of the Congestion Assistant on the traffic flow. This microscopic traffic flow model was found to be a suitable tool for this. It is able to represent the behaviour of vehicles equipped with the Congestion Assistant and their interactions with other (non-)equipped vehicles on a congested motorway section. As with any model, its value largely depends on the resemblance with the real-world. In this study, the reference situation in the ITS Modeller was calibrated and validated using 1-minute speed and flow data measured on the Dutch A12 motorway. The results showed a satisfactory resemblance between the empirical and the simulated traffic flow data, particularly with respect to the onset of congestion. Nonetheless, the further development of the ITS Modeller could benefit from more validation. For example, on the level of individual drivers the variance in driving behaviour could be better incorporated. This does not only concern the parameter settings, but also the modelling assumptions. For example, the car-following model could be enhanced by distinguishing different driving behaviour in congested and non-congested situations. This would probably also improve the simulated behaviour at the recovery from the jam.

A diversity of measures was used to study the impacts of the Congestion Assistant on traffic efficiency and traffic safety. These measures gave insight into the system's performance in a traffic flow where equipped and non-equipped vehicles interact with each other. However, other measures are necessary to gain more detailed information about the working of the functions of the Congestion Assistant in the traffic flow. For example, the standard deviation of deceleration can provide more knowledge of the effects of the Active pedal on anticipating the jam. Also 'zooming in' on one or more vehicles during the simulation run and collecting data of these vehicles would enhance the understanding of the traffic flow effects. This 'zoom in' possibility does not yet exist in the ITS Modeller and it is recommended to include such feature.

Different variants of the Congestion Assistant were studied. Especially, the Stop & Go variants positively influenced the throughput of the traffic flow. In this study, two different time headway settings were examined. It would be interesting to also examine other characteristics of a Stop & Go, such as the acceleration range and the contribution of vehicle-vehicle communication. The Stop & Go in this research supports the driver without deceleration and acceleration limitations. However, for the moment, it is expected that such systems will be restricted to a certain acceleration range (e.g. between -3 m/s^2 and +1.5 m/s^2), so that sometimes the driver needs to intervene. Another acceleration algorithm might also lead to safer braking and following behaviour, recalling the rather high percentages of hard braking and small TTCs with the current algorithm. Furthermore, in the longer run, it is expected that vehicles will be able to communicate with each other. Through the exchange of information with predecessors, a Stop & Go could further increase the traffic performance by more efficient following behaviour. In the Integrated full-Range Speed Assistant (IRSA) project, for example, a clear added value of vehicle-vehicle communication was found, especially when vehicles equipped with IRSA approached a traffic jam (Van Arem et al., 2007).

Compared to the Stop & Go variants, the Active pedal variants showed smaller positive effects on traffic efficiency, although these variants increased traffic safety due to a smoother approach to the traffic jam. One reason for the small throughput effects might be the deceleration capacity of the Active pedal, which was restricted to -1 m/s^2. Some preliminary simulations with an Active pedal that can decelerate with a maximum of -5 m/s^2 showed to reduce the amount of congestion much more than the current implementation. So it seems that versions of the Active pedal with a less conservative deceleration capacity (and acting like an Active brake pedal rather than an Active gas pedal) could enhance traffic efficiency better. Furthermore, the Active pedal in this study assumes communication between all vehicles for locating a traffic jam and compliance of the driver with a proposed deceleration. It would be interesting to examine the impacts of only communication between equipped vehicles and less compliance of the driver (as seen in the driving simulator experiment). However, the impacts of the current implementation of the Active pedal on the traffic flow are already small, so it is expected that these adaptations will lead to even smaller impacts.

The Congestion Assistant was tested in specific congested traffic situations due to a left lane drop from 4 to 3 lanes. There are more motorway bottlenecks that can cause traffic breakdown, such as on-ramps and weaving sections. Congestion might develop differently per bottleneck. It would be interesting to investigate to what extent the observed effects of the Congestion Assistant prevail in other congested motorway situations.

8.6 Conclusions

This chapter presented the results from a microscopic traffic simulation study into the impacts of the Congestion Assistant on the traffic flow. Several variants of the system with different equipment rates were analysed on a four-lane motorway with a lane drop. The Congestion Assistant became operative after the start of a traffic jam and affected the further development of the jam. The Active pedal of the system slowed down the driver when approaching the jam at too high speed, while the Stop & Go took over the longitudinal driving task in the jam.

It appeared that both the Active pedal and the Stop & Go have positive effects on the dissipation of traffic jams, but the effects due to the Stop & Go are much larger. Combining the two functions did not lead to better results on traffic efficiency compared to the results of the single functions. In fact, the Active pedal showed no added value when it is combined with the Stop & Go. All variants of the Congestion Assistant reduced the amount of congestion, hereby also decreasing the speed variation, indicating a more stable, homogeneous and safe traffic flow. The Active pedal further increased traffic safety by less hard braking actions and less unsafe following situations when approaching a jam. The Stop & Go, on the other hand, showed more hard braking actions and more potentially unsafe following situations in the jam due to rather fierce acceleration behaviour. Combining the Stop & Go and the Active pedal decreases the percentages of hard braking and small TTCs compared to only the Stop & Go.

In summary, the Congestion Assistant showed to compensate for the unfavourable human behaviour that (also) causes congestion. The Active pedal smoothed the traffic flow when approaching a traffic jam by inducing better anticipation behaviour of the driver. Vehicles equipped with the Stop & Go followed other vehicles more efficiently when driving in and leaving a jam by maintaining smaller headways and eliminating the reaction time of drivers. Especially the Stop & Go reduced the amount of congestion significantly. At the same time, this function also increased the amount of hard braking. Adapting the acceleration algorithm of the Stop & Go will presumably compensate for this effect.

Chapter 9

Conclusions and recommendations

The objective of this research was to gain more insight into the user needs for driver assistance and consequently, into the impacts of the so-called Congestion Assistant on the driver and the traffic flow. This final chapter discusses the outcome of the total research project. It starts with a review of the results from the previous chapters by answering the research questions posed in Chapter 1. Next, some directions for further research are discussed. The chapter ends with general implications and conclusions.

9.1 Overview of results

The first objective of this research was to gain more knowledge of the driver's point of view towards intelligent vehicles. The second objective was to assess the behavioural responses of the driver to the Congestion Assistant, an in-vehicle system that was developed based on in this research observed user needs for driver assistance. The third objective was to assess the influence of the Congestion Assistant on traffic flow characteristics. This section draws the main conclusions concerning these objectives by answering the three corresponding research questions:

- What are the needs of the driver with respect to driver assistance?
- What are the impacts of the Congestion Assistant on the driver, in terms of driving behaviour, mental workload and acceptance?
- What are the impacts of the Congestion Assistant on the traffic flow, in terms of traffic efficiency and traffic safety?

9.1.1 User needs for driver assistance

A user needs survey was conducted to investigate the perceived needs for driver assistance. In contrast to earlier surveys that generally concentrated on 'ready to use' driver support systems, our survey focused on assistance with several driving tasks and situations, and desired combinations thereof. This enabled a better understanding of when and how car drivers want to be assisted by their cars during driving.

The results of the user needs survey are based on the answers of 1049 Dutch respondents that completed the survey on the Internet. In the first part of the survey, they had to express their needs for a variety of driver support functions. The respondents particularly favoured warnings for downstream traffic conditions, such as congestion and accidents, and warnings for traffic in blind spots, for example when changing lanes or approaching an intersection. This shows that drivers appreciate being well informed when driving. Furthermore, driver assistance on motorways was preferred to assistance on rural roads and urban roads. This has probably to do with the complexity of the traffic process, being least complex on motorways. It is likely that drivers assume to be best assisted by a system that is well capable of detecting and interpreting the driving environment. Automatic actions from the car were generally not appreciated. However, one exception to this was congestion driving. Apparently, drivers do not make a problem of handing over control to the car during such an uncomfortable driving task. In the second part of the survey, the respondents had to formulate their ideal driver support system by choosing a limited number of driving tasks and situations to be supported by this system. The ideal system seems to be personal, since the respondents chose various driving tasks and situations that the system should provide assistance with. The majority of respondents, however, preferred the ideal system to give support with reduced visibility and imminent crash situations. This shows that drivers value help from their cars in potentially dangerous situations.

The observed user needs have implications for the design of driver support systems. To fit these needs, systems should integrate several forms of driver assistance, for example by exchanging information between vehicles and using one user interface. This also applies to the Congestion Assistant, which was developed based on the survey results. The system consists of a mix of informing, assisting and controlling functions to support the driver during congested traffic situations on motorways:

- Warning & Information: the driver receives warnings about a traffic jam ahead and information about the length of the jam when driving in it.
- Active pedal: the driver feels a counterforce of the gas pedal when approaching the jam at too high speed.
- Stop & Go: the system takes over the longitudinal driving task from the driver when driving in the jam.

9.1.2 Impacts of Congestion Assistant on driver

A driving simulator experiment was performed to examine the impacts of the Congestion Assistant on the driver in terms of driving behaviour, mental workload and acceptance. Not only the assessment of the total system was of interest, but also the assessment of the separate functions. The results of the experiment are based on 37 participants who completed four experimental runs with and without the Congestion Assistant during normal visibility conditions and in fog. These participants were selected from the respondents to the user needs survey, so that their needs for congestion assistance in general could be studied in relation to their acceptance of the Congestion Assistant.

The Congestion Assistant appeared to influence driving behaviour, except for the Warning function. This might be explained by the fact that the participants were still relatively far away from the traffic jam (i.e. 5-1.5 km before the jam) when they received the congestion warnings. The Active pedal resulted in earlier decelerations expressed by lower mean speeds and safer car-following behaviour expressed by larger time headways and larger Time-To-Collision (TTC) values when approaching the traffic jam. This shows that the driver better anticipates the downstream jam due to the Active pedal. The Stop & Go led to smaller time headways, smaller TTCs and smaller standard deviations of time headway in the traffic jam, indicating a more efficient car-following behaviour. After the traffic jam, the mean time headway was smaller when one had driven with the Congestion Assistant compared to driving without the system. Probably, the driver gets used to driving at short time headways because the Stop & Go also displays this behaviour in the traffic jam.

The participants experienced a lower mental workload with the total Congestion Assistant, but only when driving in fog. During normal visibility, the system did not affect the experienced workload. Furthermore, the results showed that the mental workload was higher with the Active pedal than without this function. This could be due to an increase in the driver's attention to the upcoming traffic jam or to the pedal itself giving a 'sudden' counterforce. The Stop & Go, on the other hand, resulted in a lower mental workload. Although this function takes over part of the driving task, it is important that the driver stays alert, so that situations of 'underload' are avoided.

The acceptance of the total Congestion Assistant was fairly high: an average score of 1.0 on a scale from -2 to +2. However, not all functions of the system were equally appreciated. Particularly the Warning & Information and the Stop & Go were highly valued. The acceptance of the Stop & Go significantly increased after having gained experience with the system. This shows that the driver appreciates being released from the uncomfortable task of congestion driving by the Stop & Go. The expectation that the Congestion Assistant would be accepted more in fog than during normal visibility was not confirmed by the results. Participants who held a positive attitude towards congestion assistance – based on their survey answers – were more positive about the Congestion Assistant than participants with a negative attitude. The indicated user needs especially corresponded to how satisfying one thinks a system would be. Thus, expressing user needs for driver assistance can be considered a condition for actually accepting the in-vehicle technology. It was therefore concluded that the user needs survey revealed to be a valid method for the indication of user needs for congestion assistance. Furthermore, the participants were likely to buy the Congestion Assistant. The higher one rated the acceptance of the system, the more one indicated to be willing to buy it. Thus, evaluating a driver support system as acceptable can be considered a condition for actually purchasing it.

To summarize the driving simulator results, the Congestion Assistant showed promising improvements in traffic safety when approaching a traffic jam due to the Active pedal, although the participants did not express great appreciation of this function. Furthermore, positive effects on traffic safety and traffic efficiency in a jam can be expected by the Congestion Assistant due to the Stop & Go, a function which was highly appreciated by the participants.

9.1.3 Impacts of Congestion Assistant on traffic flow

A microscopic traffic simulation study was conducted to assess the impacts of the Congestion Assistant on the traffic flow in terms of traffic efficiency and traffic safety. It was investigated whether the observed effects in the driving simulator experiment would prevail when focusing on a traffic flow instead of only one driver. Since the Warning function of the Congestion Assistant did not affect driving behaviour, the system in this traffic simulation study included either the Active pedal or the Stop & Go or a combination of both functions. The impacts of the separate functions as well as the contributions of these functions to the results of the combined version of the Congestion Assistant were studied. The results are based on six variants of the Congestion Assistant that were studied at two equipment rates and compared to the reference situation in which no vehicles were equipped with the system. The simulated road consisted of a four-lane motorway segment with a left lane drop that caused congestion. The reference situation was calibrated and validated with data measured on the Dutch A12 motorway and showed a satisfactory resemblance with respect to the congestion build-up.

All variants of the Congestion Assistant resulted in less congestion and higher queue discharge flows in comparison with the reference situation. The Active pedal caused a reduction in the amount of congestion by intervening in approaching a jam, this way reducing the congestion inflow. However, a much bigger reduction in the amount of congestion was obtained by the Stop & Go. This function intervened in driving in a jam and showed a more efficient car-following behaviour. Thus, both functions have positive effects on the dissipation of jams, but the effects due to the Stop & Go are much larger. Higher equipment rates of the Congestion Assistant caused larger positive effects on traffic efficiency. The combined variants of the Congestion Assistant, consisting of an Active pedal and a Stop & Go, were not found to lead to better results than the single variants with either an Active pedal or a Stop & Go. In fact, the results of the combined variants were very similar to those of the Stop & Go variants. This means that the Active pedal has no added value with respect to traffic efficiency when it is combined with the Stop & Go.

It was expected that the Congestion Assistant would lead to a more stable and homogeneous flow, indicating positive effects on traffic safety. This can be confirmed based on the speed variation data. All variants of the Congestion Assistant resulted in less congestion, which was reflected by smaller standard deviations of speed than found in the reference situation. Generally, the higher the equipment rate of the Congestion Assistant, the larger were the positive effects on traffic safety with respect to speed variation. Concerning the Active pedal variants, it also led to an improvement of traffic safety in terms of less hard braking actions and less unsafe following situations. But a higher equipment rate of the Congestion Assistant consisting of only a Stop & Go might decrease traffic safety, especially due to the higher percentage of hard braking. Similar to the results on traffic efficiency, the results on traffic safety were not found to be better when the Congestion Assistant consisted of both an Active pedal and a Stop & Go compared to only one of these functions. Including the Stop & Go in the Congestion Assistant resulted in large positive effects on speed variation, but it also led to large negative effects on the occurrence of hard braking situations. The Active pedal does not add to larger positive effects on speed variation compared to a Congestion Assistant with only a Stop & Go. On the other hand, adding an Active pedal to the Stop & Go decreases the percentages of hard braking and small TTCs, although it does not lead to larger positive effects on these percentages compared to a Congestion Assistant consisting of only an Active pedal.

To summarize the traffic simulation results, the Congestion Assistant showed to compensate for the unfavourable human behaviour that (also) causes congestion. The Active pedal smoothed the traffic flow when approaching a traffic jam by inducing better anticipation behaviour of the driver compared to unsupported drivers. This had a small effect on the dissipation of congestion, rather it affected traffic safety by a safer approach to the jam. Vehicles equipped with the Stop & Go followed other vehicles more efficiently than non-equipped vehicles when driving in and leaving a jam by maintaining smaller headways and eliminating the reaction time of drivers. This reduced the amount of congestion significantly. For instance, the average speed at 750 m before the lane drop was 82 km/h (102 km/h) when 10% (50%) of the vehicles were equipped with the Stop & Go compared to 63 km/h in the reference situation. At the same time, this function also increased the amount of hard braking. Adapting the acceleration algorithm of the Stop & Go will presumably compensate for this effect.

9.2 Further research

Basically, three research methodologies were used to provide answers to the research questions: survey, driving simulator and traffic simulation. This section discusses some directions for further research related to the issues that came across during these research parts. These issues concern both content and methodology.

9.2.1 Survey and user needs

The user needs survey in this thesis reflected the needs of the driver with respect to driver assistance. Based on the results, one can expect that integrated driver support systems are sensible. However, more research into user needs for integrated systems is advisable. For example, in our survey the respondents had to formulate their ideal system by making a trade-off between the driving tasks and situations that the system should support. For future research, it is recommended to formulate the ideal system on a more detailed level in terms of driver support functions instead of driving tasks and situations.

Our survey was distributed via the Internet. Despite the many benefits, selection bias can be regarded as a drawback of Internet questionnaires. Up to now, the Internet is less accessible to elderly people. Therefore, the opinion of an important group of drivers was missing in this user needs survey. Further research should concentrate on this group, preferably using other data collection methods (e.g. face-to-face interviews, paper questionnaires).

The user needs survey included questions about the needs for driver support functions and the design of an ideal driver support system. This approach provided more insight into when and how car drivers want to be assisted by their cars during driving. However, it did not enable to study why exactly the respondents indicated these needs. For example, are the needs related to perceived difficulties of certain driving tasks or perceived risks of technology failure? Other (follow-up) methodologies might be better suited to provide this insight, such as in-depth interviews and focus groups.

9.2.2 Driving simulator and impacts on the driver

The participants gained experience with the Stop & Go of the Congestion Assistant in the driving simulator. In the traffic jam, the system maintained a time headway of 1.0 s. Although the participants would maintain a larger time headway themselves, they expressed great appreciation of the Stop & Go. Hence they accept closely following other vehicles in a traffic jam. However, these findings do not tell whether drivers will accept being closely followed by others. Further research is needed to study this aspect, preferably in a field study for its high validity.

Next to driving behaviour and mental workload, acceptance of and willingness to buy the Congestion Assistant were studied in a driving simulator, since the system is not available on the market. This provided valuable information about the initial reactions of drivers to the system. However, actual purchase and usage behaviour could not be examined. Future studies should therefore focus on factors influencing the purchase and usage of in-vehicle systems in reality.

Relations between user needs for congestion assistance and acceptance of the Congestion Assistant were investigated. It was found that expressing user needs for driver assistance can be considered a condition for actually accepting this technology. It might be interesting to also study possible relations between user needs and driving behaviour or mental workload. For example, drivers with a negative attitude towards congestion assistance might react differently to the Congestion Assistant, for instance showing less obedience to the Active pedal or a higher mental workload during the Stop & Go. To elaborate on this, a larger sample of participants with emphasis on driver characteristics, such as gender and age, would enable to examine whether these characteristics also affect the behavioural reactions to the Congestion Assistant.

When approaching the traffic jam with the Congestion Assistant, the driver could simultaneously receive congestion warnings on the display by the Warning function and feel a counterforce of the gas pedal by the Active pedal. However, it was assumed that particularly the Active pedal affected the driving behaviour in this situation, since it was more compelling than the Warning function. To verify this assumption, more knowledge is desired of the influence of congestion warnings alone on driving behaviour when running into congestion.

In the driving simulator experiment, but also in the traffic simulation study, the safety effects of the Congestion Assistant were assessed using indicators, such as time headway and Time-To-Collision (TTC). These indicators have generally accepted boundaries on what is safe or not. For example, time headways smaller than 1 s and TTCs smaller than 4 s indicate potentially dangerous situations. However, it was noted that small time headways or TTCs during automatic driving can be considered less dangerous than small values during manual driving, since the automatic system (e.g. the Stop & Go) is able to eliminate undesirable human behaviour, such as large reaction times. Further research is needed to develop adequate safety indicators and to come to new accepted boundaries for safety to fairly compare manual and supported driving.

9.2.3 Traffic simulation and impacts on the traffic flow

The traffic flow effects of the Congestion Assistant were assessed using the ITS Modeller. The simulated data concerning the onset of congestion showed a satisfactory resemblance with empirical data. However, further model calibrations and adaptations are desired to improve the simulation outcomes in congested traffic conditions, for example by including more variance of individual driving behaviour in congestion. Moreover, the ITS Modeller could benefit from the development of more traffic flow indicators, such as shockwave information and statistics related to an in-vehicle system (e.g. information about the time and location that the system was active).

In Chapter 8, it was suggested to also study other versions of the Stop & Go and the Active pedal. To elaborate on this, the Congestion Assistant could be extended towards a full speed range support system. For example, the Active pedal could operate like an ACC: instead of giving haptic feedback, it might automatically regulate speed using throttle and brake. And besides taking into account the tail of a traffic jam, it would take into account the predecessor and regulate the headway accordingly. This way, the longitudinal control of the ACC / Stop & Go is based on the traffic situation ahead, so that the driver (or better: the vehicle) can anticipate a jam, before the driver is able to see it. Another challenge is to adapt the working of the Congestion Assistant in such a way that it behaves more as a proactive system trying to avoid the onset of congestion instead of the current reactive system that starts acting after a traffic jam has been formed. Of course, these suggestions for the Congestion Assistant differ significantly from the version that has been studied in this research. Therefore, the impacts of such new versions on the traffic flow, but also on the driver, should be thoroughly investigated.

9.3 Implications and conclusions

This research resulted in more insight into the user needs for driver assistance and the impacts of the so-called Congestion Assistant on the driver and the traffic flow. First, the user needs survey illustrated that drivers have a great need for their cars giving congestion warnings and taking over the driving task in congestion. These results were used to create the Congestion Assistant. Consequently, this system is based on driver preferences contrary to earlier research that particularly focused on technological possibilities. Next, the driving simulator experiment showed that the Congestion Assistant leads to significant improvements in driving performance due to the Active pedal (before the jam) and the Stop & Go (in the jam). Drivers particularly appreciate the Warning function of the system and the Stop & Go, but they are less positive about the Active pedal. Finally, the microscopic traffic simulation study demonstrated that especially the Stop & Go reduces the amount of congestion significantly. The Active pedal hardly influences traffic efficiency, rather it affects traffic safety through a safer approach to the jam.

The promising results above give rise to speeding up the further development of the Congestion Assistant. This research has removed part of the uncertainty surrounding the slow market introduction of intelligent vehicles. For the automotive industry, it reduced the uncertainty about the needs for driver assistance in general and the Congestion Assistant in particular. At the same time, it reduced the uncertainty for public authorities about the impacts of the Congestion Assistant on traffic safety and traffic efficiency. Following from this research, there is a clear win-win situation for both parties to cooperate with respect to the further development of the Congestion Assistant. This is also in line with the Intelligent Car Initiative of the European Commission that aims at a faster take-up of driver support systems in the market. This research contributed to the objectives of the Intelligent Car Initiative by creating awareness of driver assistance and by examining and publishing the effects of the Congestion Assistant on the driver and the traffic flow.

Current research and development efforts are mostly focused on cooperative systems that are able to communicate with each other and the infrastructure. These systems can, for example, provide detailed information about the traffic conditions ahead. The Warning function and the Active pedal of the Congestion Assistant are also assumed to have knowledge of what is happening further down the road. Such applications will probably become available after 2010, the year that the frequency band for vehicle-vehicle communication should be allocated, as far as the Car 2 Car Communication Consortium is concerned. Until then, the efforts should also be focused on promising autonomous applications, such as the Stop & Go of the Congestion Assistant. For the automotive industry, it is relevant to know that people are willing to hand over the driving task in congestion to their cars. For public authorities, it is important to realize that the Stop & Go shows significant impacts on the dissipation of traffic jams. In view of the severe congestion problems in Europe, it is recommended that both parties work together and in the short run come to a system that serves all interests, including those of the driver, best.

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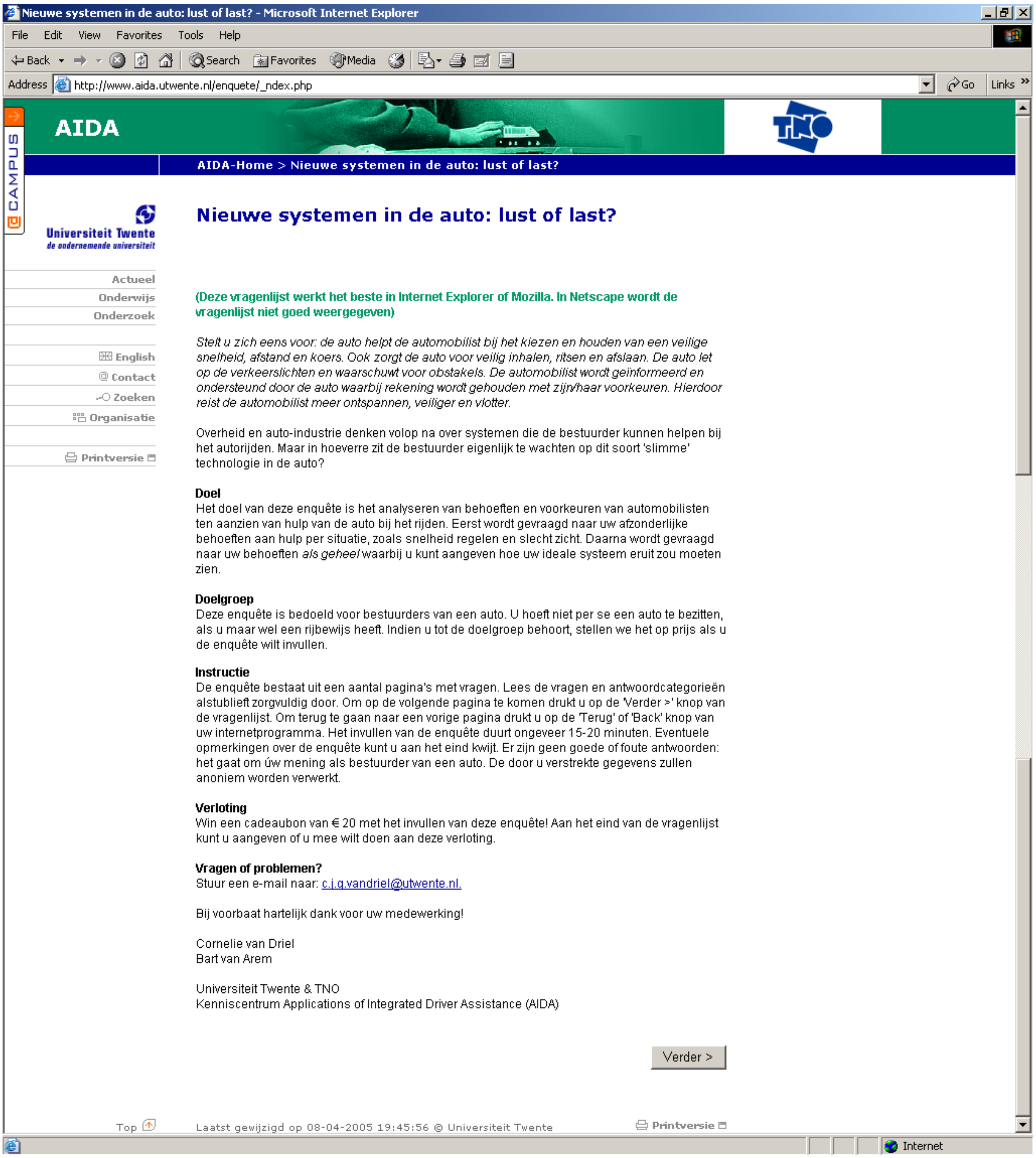
Appendix A

User needs survey

This appendix shows the computer screens of the user needs survey when it was online on the Internet. The survey was in Dutch.

Introduction



Nieuwe systemen in de auto: lust of last?

(Deze vragenlijst werkt het beste in Internet Explorer of Mozilla. In Netscape wordt de vragenlijst niet goed weergegeven)

Stelt u zich eens voor: de auto helpt de automobilist bij het kiezen en houden van een veilige snelheid, afstand en koers. Ook zorgt de auto voor veilig inhalen, ritsen en afslaan. De auto let op de verkeerslichten en waarschuwt voor obstakels. De automobilist wordt geïnformeerd en ondersteund door de auto waarbij rekening wordt gehouden met zijn/haar voorkeuren. Hierdoor reist de automobilist meer ontspannen, veiliger en vlotter.

Overheid en auto-industrie denken volop na over systemen die de bestuurder kunnen helpen bij het autorijden. Maar in hoeverre zit de bestuurder eigenlijk te wachten op dit soort 'slimme' technologie in de auto?

Doel
Het doel van deze enquête is het analyseren van behoeften en voorkeuren van automobilisten ten aanzien van hulp van de auto bij het rijden. Eerst wordt gevraagd naar uw afzonderlijke behoeften aan hulp per situatie, zoals snelheid regelen en slecht zicht. Daarna wordt gevraagd naar uw behoeften *als geheel* waarbij u kunt aangeven hoe uw ideale systeem eruit zou moeten zien.

Doelgroep
Deze enquête is bedoeld voor bestuurders van een auto. U hoeft niet per se een auto te bezitten, als u maar wel een rijbewijs heeft. Indien u tot de doelgroep behoort, stellen we het op prijs als u de enquête wilt invullen.

Instructie
De enquête bestaat uit een aantal pagina's met vragen. Lees de vragen en antwoordcategorieën alstublieft zorgvuldig door. Om op de volgende pagina te komen drukt u op de 'Verder >' knop van de vragenlijst. Om terug te gaan naar een vorige pagina drukt u op de 'Terug' of 'Back' knop van uw internetprogramma. Het invullen van de enquête duurt ongeveer 15-20 minuten. Eventuele opmerkingen over de enquête kunt u aan het eind kwijt. Er zijn geen goede of foute antwoorden: het gaat om úw mening als bestuurder van een auto. De door u verstrekte gegevens zullen anoniem worden verwerkt.

Verloting
Win een cadeaubon van € 20 met het invullen van deze enquête! Aan het eind van de vragenlijst kunt u aangeven of u mee wilt doen aan deze verloting.

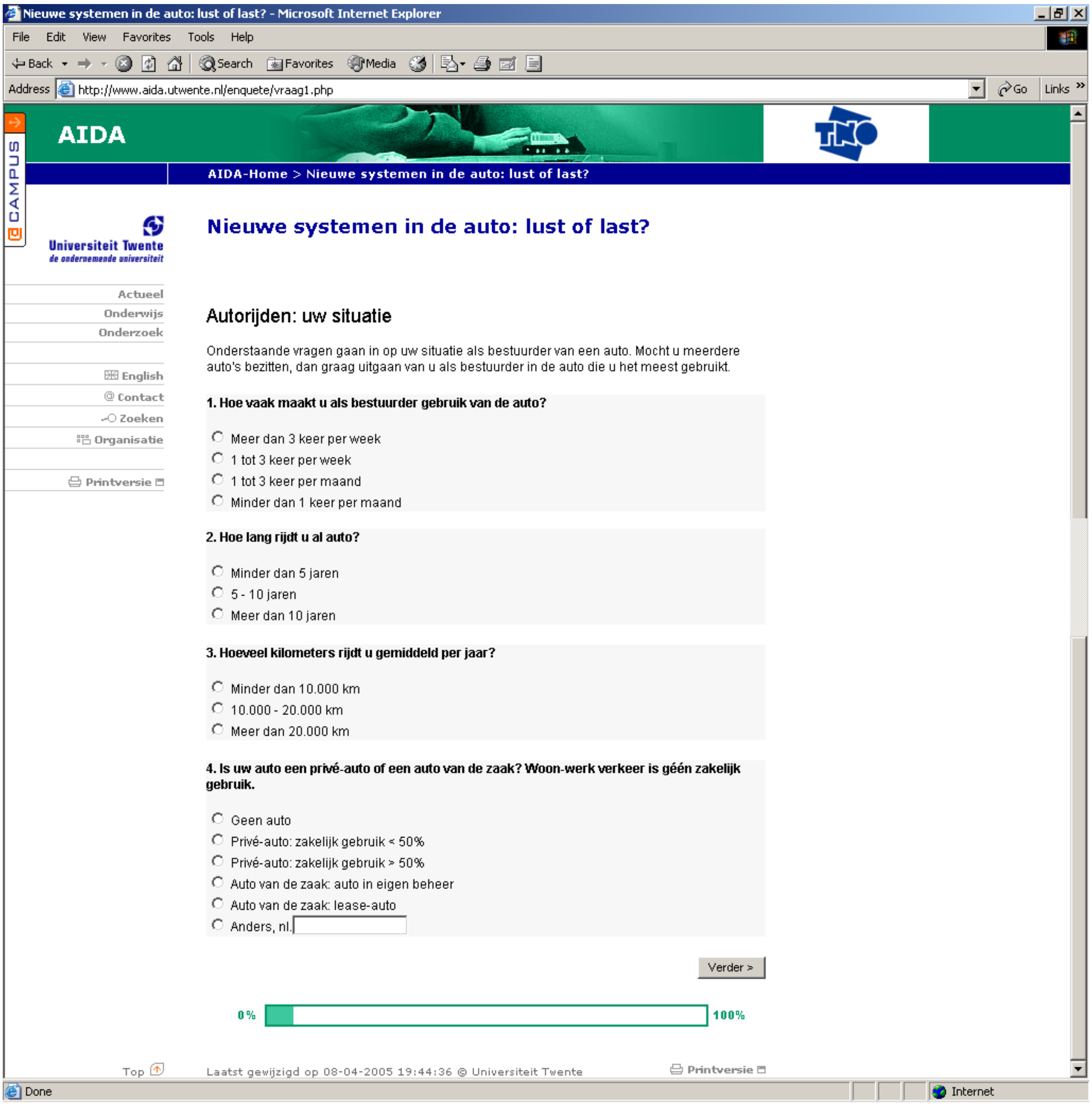
Vragen of problemen?
Stuur een e-mail naar: c.j.g.vandriel@utwente.nl.

Bij voorbaat hartelijk dank voor uw medewerking!

Cornelie van Driel
Bart van Arem

Universiteit Twente & TNO
Kenniscentrum Applications of Integrated Driver Assistance (AIDA)

Background questions



Nieuwe systemen in de auto: lust of last?

Autorijden: uw situatie

Onderstaande vragen gaan in op uw situatie als bestuurder van een auto. Mocht u meerdere auto's bezitten, dan graag uitgaan van u als bestuurder in de auto die u het meest gebruikt.

1. Hoe vaak maakt u als bestuurder gebruik van de auto?

○ Meer dan 3 keer per week
○ 1 tot 3 keer per week
○ 1 tot 3 keer per maand
○ Minder dan 1 keer per maand

2. Hoe lang rijdt u al auto?

○ Minder dan 5 jaren
○ 5 - 10 jaren
○ Meer dan 10 jaren

3. Hoeveel kilometers rijdt u gemiddeld per jaar?

○ Minder dan 10.000 km
○ 10.000 - 20.000 km
○ Meer dan 20.000 km

4. Is uw auto een privé-auto of een auto van de zaak? Woon-werk verkeer is géén zakelijk gebruik.

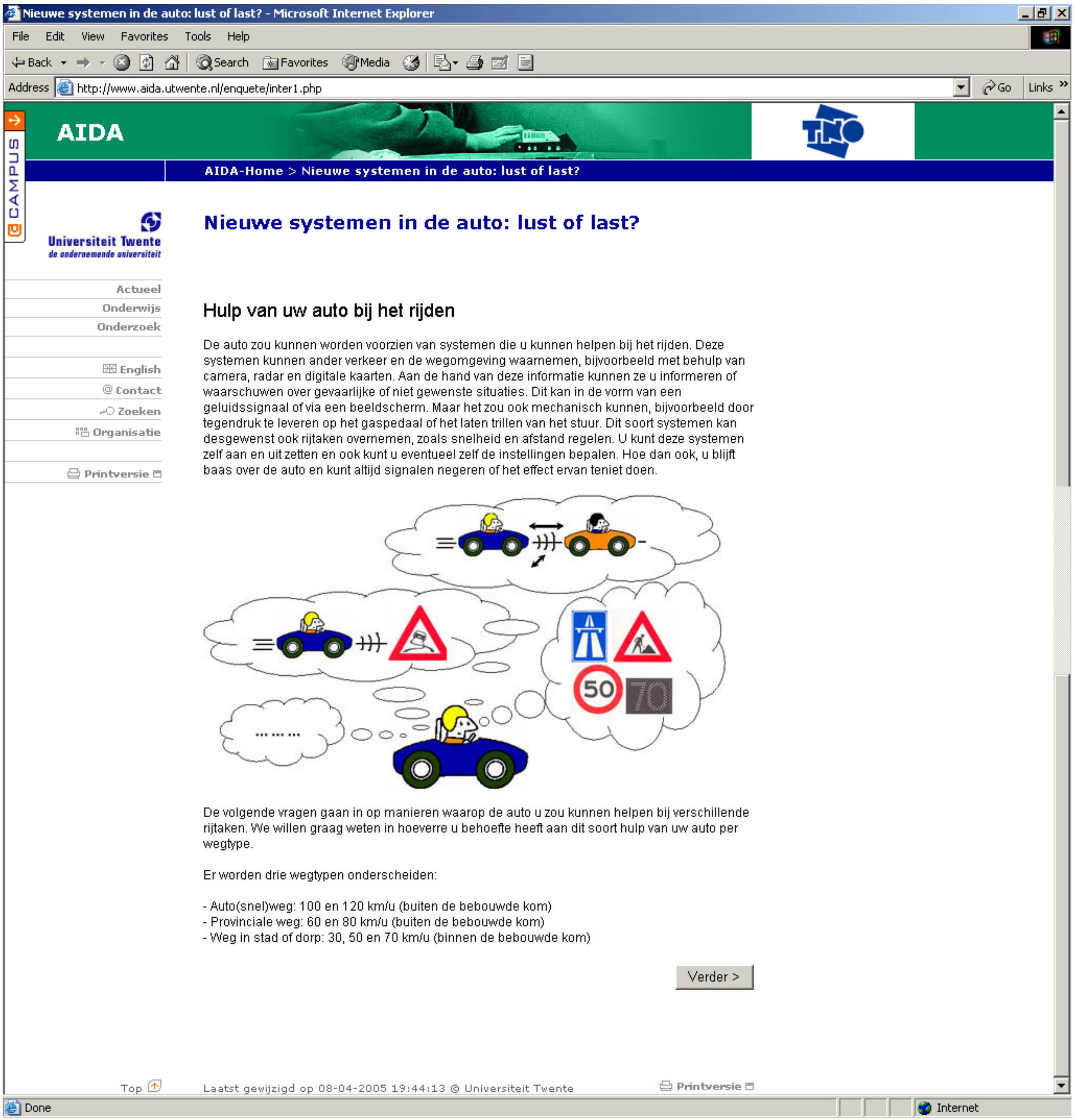
○ Geen auto
○ Privé-auto: zakelijk gebruik < 50%
○ Privé-auto: zakelijk gebruik > 50%
○ Auto van de zaak: auto in eigen beheer
○ Auto van de zaak: lease-auto
○ Anders, nl. ______

Verder >

0% 100%

Laatst gewijzigd op 08-04-2005 19:44:36 © Universiteit Twente

Information about help from the car during driving



Nieuwe systemen in de auto: lust of last?

Hulp van uw auto bij het rijden

De auto zou kunnen worden voorzien van systemen die u kunnen helpen bij het rijden. Deze systemen kunnen ander verkeer en de wegomgeving waarnemen, bijvoorbeeld met behulp van camera, radar en digitale kaarten. Aan de hand van deze informatie kunnen ze u informeren of waarschuwen over gevaarlijke of niet gewenste situaties. Dit kan in de vorm van een geluidssignaal of via een beeldscherm. Maar het zou ook mechanisch kunnen, bijvoorbeeld door tegendruk te leveren op het gaspedaal of het laten trillen van het stuur. Dit soort systemen kan desgewenst ook rijtaken overnemen, zoals snelheid en afstand regelen. U kunt deze systemen zelf aan en uit zetten en ook kunt u eventueel zelf de instellingen bepalen. Hoe dan ook, u blijft baas over de auto en kunt altijd signalen negeren of het effect ervan teniet doen.

De volgende vragen gaan in op manieren waarop de auto u zou kunnen helpen bij verschillende rijtaken. We willen graag weten in hoeverre u behoefte heeft aan dit soort hulp van uw auto per wegtype.

Er worden drie wegtypen onderscheiden:

- Auto(snel)weg: 100 en 120 km/u (buiten de bebouwde kom)
- Provinciale weg: 60 en 80 km/u (buiten de bebouwde kom)
- Weg in stad of dorp: 30, 50 en 70 km/u (binnen de bebouwde kom)

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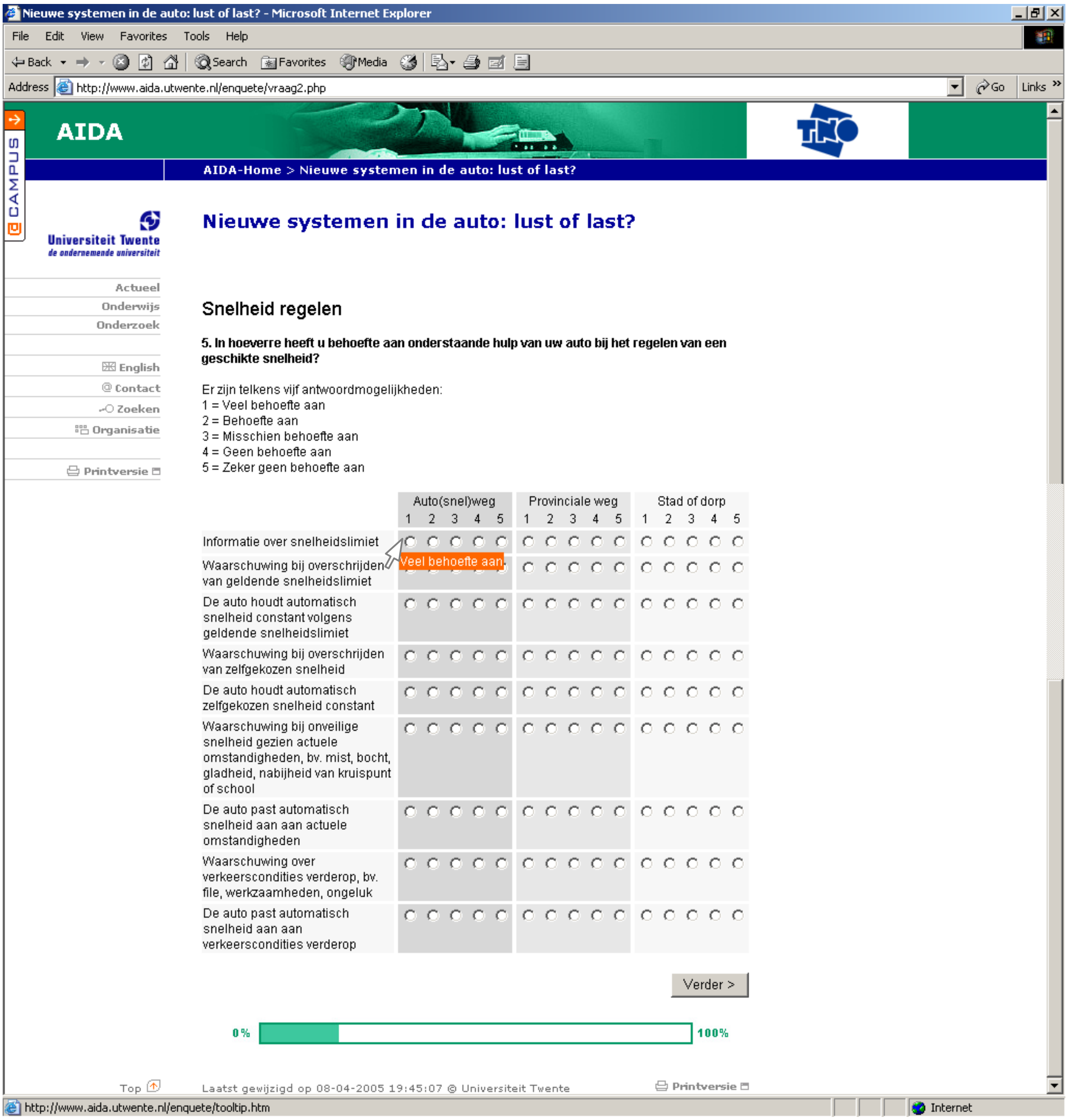
Questions about the needs for driver support functions



Nieuwe systemen in de auto: lust of last?

Snelheid regelen

5. In hoeverre heeft u behoefte aan onderstaande hulp van uw auto bij het regelen van een geschikte snelheid?

Er zijn telkens vijf antwoordmogelijkheden:
1 = Veel behoefte aan
2 = Behoefte aan
3 = Misschien behoefte aan
4 = Geen behoefte aan
5 = Zeker geen behoefte aan

	Auto(snel)weg					Provinciale weg					Stad of dorp				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Informatie over snelheidslimiet	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Waarschuwing bij overschrijden van geldende snelheidslimiet	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
De auto houdt automatisch snelheid constant volgens geldende snelheidslimiet	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Waarschuwing bij overschrijden van zelfgekozen snelheid	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
De auto houdt automatisch zelfgekozen snelheid constant	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Waarschuwing bij onveilige snelheid gezien actuele omstandigheden, bv. mist, bocht, gladheid, nabijheid van kruispunt of school	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
De auto past automatisch snelheid aan aan actuele omstandigheden	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Waarschuwing over verkeerscondities verderop, bv. file, werkzaamheden, ongeluk	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
De auto past automatisch snelheid aan aan verkeerscondities verderop	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

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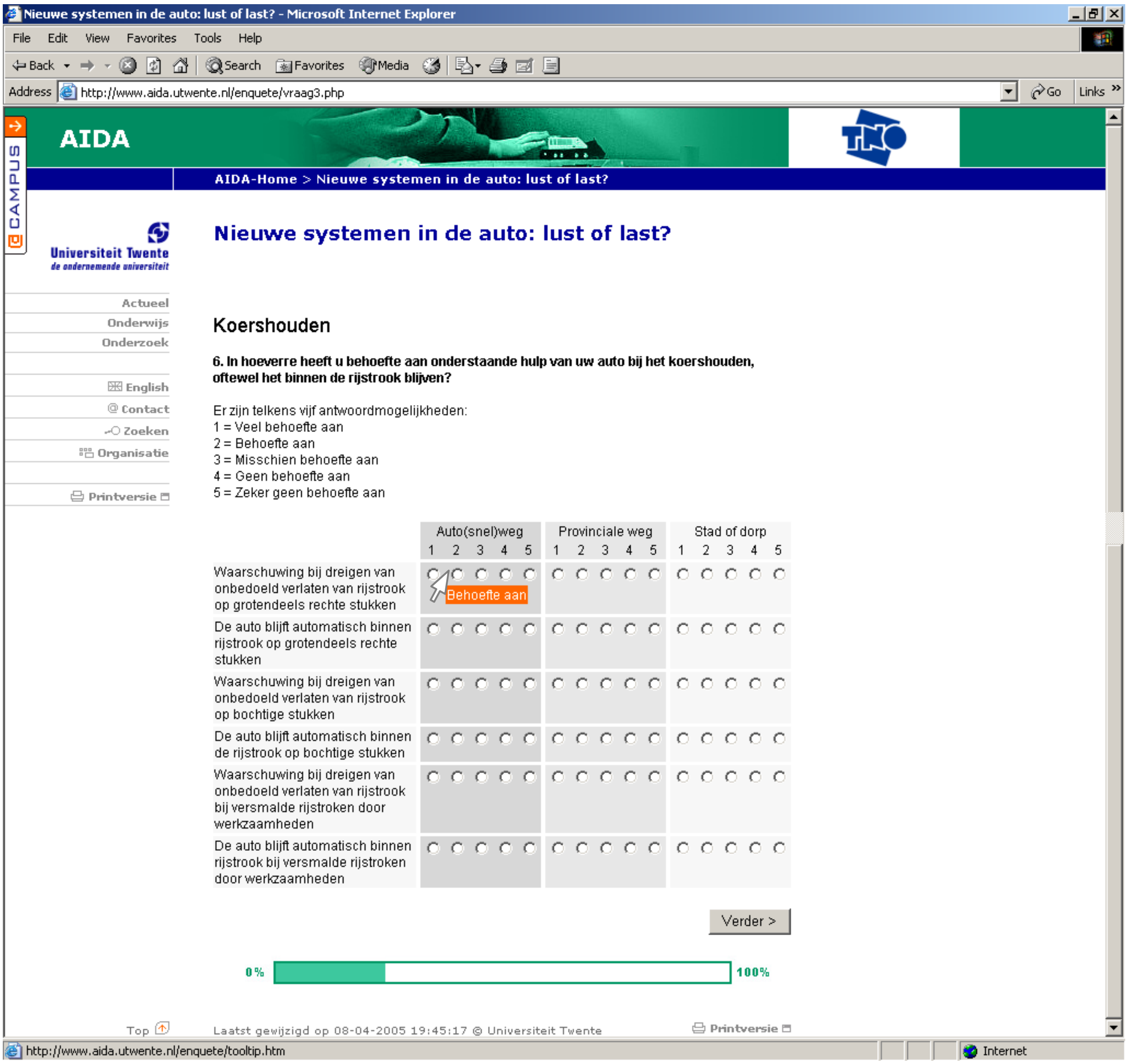


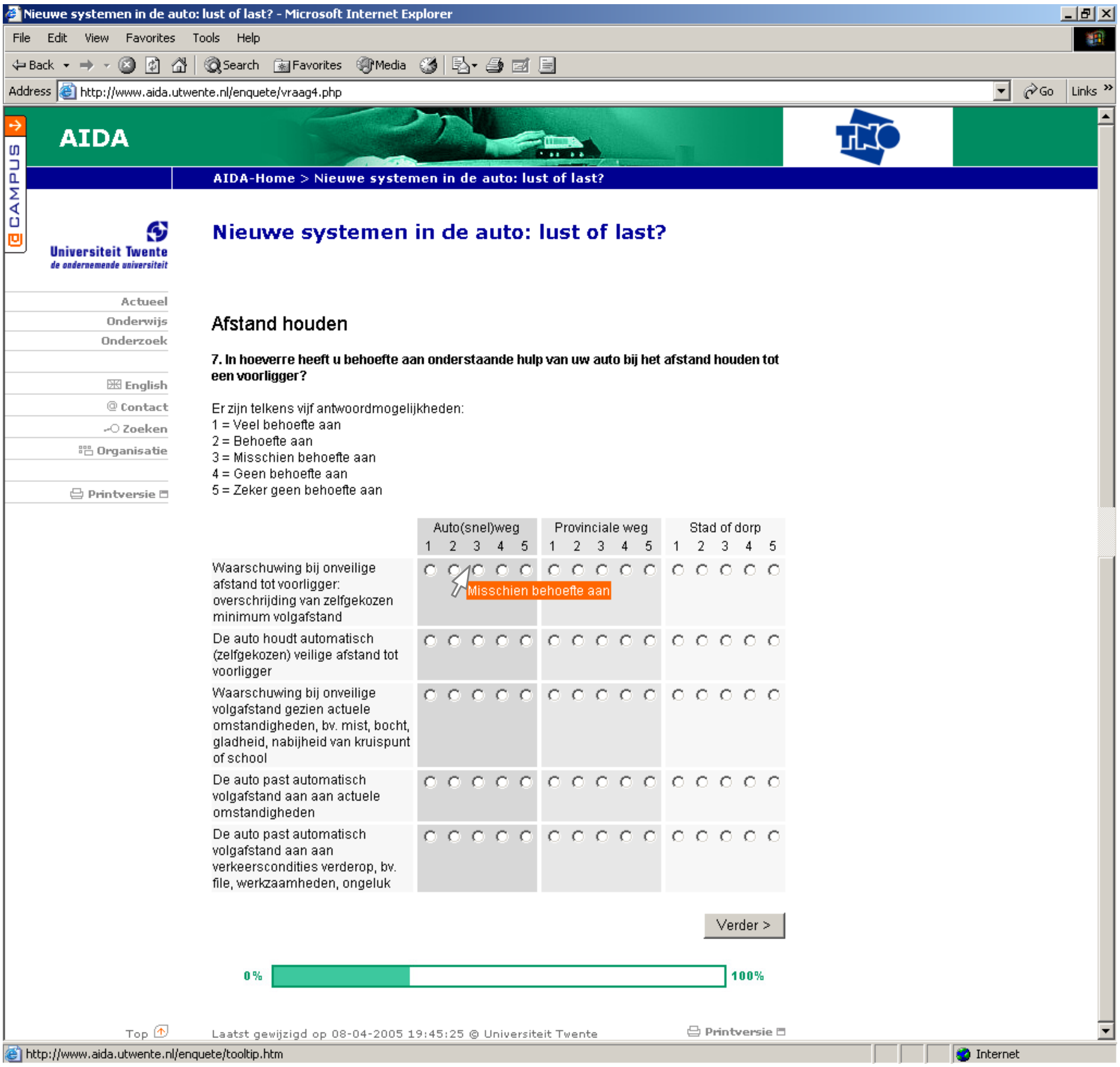
Nieuwe systemen in de auto: lust of last?

Koershouden

6. In hoeverre heeft u behoefte aan onderstaande hulp van uw auto bij het koershouden, oftewel het binnen de rijstrook blijven?

Er zijn telkens vijf antwoordmogelijkheden:
1 = Veel behoefte aan
2 = Behoefte aan
3 = Misschien behoefte aan
4 = Geen behoefte aan
5 = Zeker geen behoefte aan

	Auto(snel)weg					Provinciale weg					Stad of dorp				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Waarschuwing bij dreigen van onbedoeld verlaten van rijstrook op grotendeels rechte stukken	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
De auto blijft automatisch binnen rijstrook op grotendeels rechte stukken	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Waarschuwing bij dreigen van onbedoeld verlaten van rijstrook op bochtige stukken	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
De auto blijft automatisch binnen de rijstrook op bochtige stukken	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Waarschuwing bij dreigen van onbedoeld verlaten van rijstrook bij versmalde rijstroken door werkzaamheden	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
De auto blijft automatisch binnen rijstrook bij versmalde rijstroken door werkzaamheden	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
]



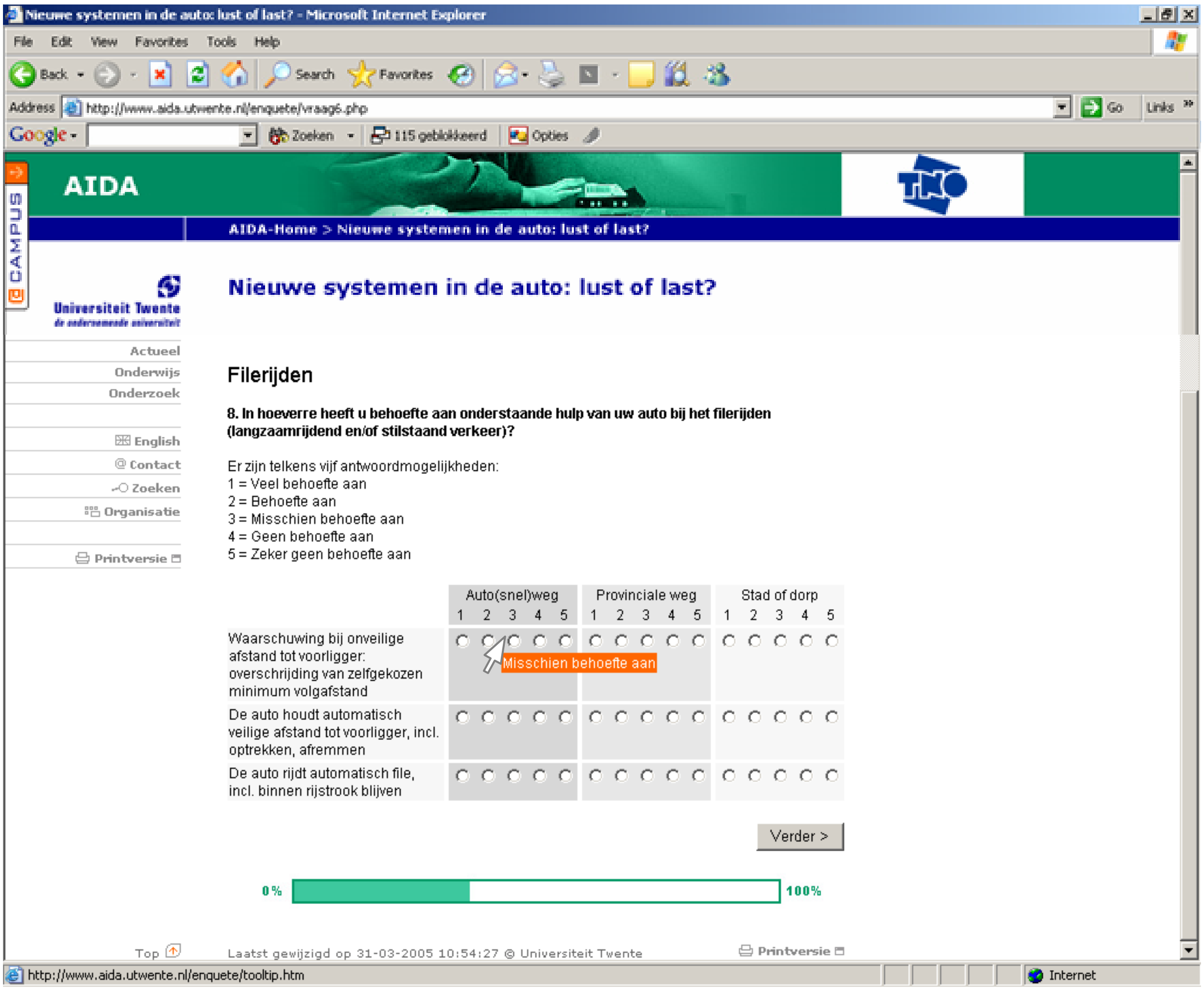
Nieuwe systemen in de auto: lust of last?

Afstand houden

7. In hoeverre heeft u behoefte aan onderstaande hulp van uw auto bij het afstand houden tot een voorligger?

Er zijn telkens vijf antwoordmogelijkheden:
1 = Veel behoefte aan
2 = Behoefte aan
3 = Misschien behoefte aan
4 = Geen behoefte aan
5 = Zeker geen behoefte aan

	Auto(snel)weg					Provinciale weg					Stad of dorp				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Waarschuwing bij onveilige afstand tot voorligger: overschrijding van zelfgekozen minimum volgafstand	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
De auto houdt automatisch (zelfgekozen) veilige afstand tot voorligger	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Waarschuwing bij onveilige volgafstand gezien actuele omstandigheden, bv. mist, bocht, gladheid, nabijheid van kruispunt of school	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
De auto past automatisch volgafstand aan aan actuele omstandigheden	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
De auto past automatisch volgafstand aan aan verkeerscondities verderop, bv. file, werkzaamheden, ongeluk	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○



Nieuwe systemen in de auto: lust of last?

Filerijden

8. In hoeverre heeft u behoefte aan onderstaande hulp van uw auto bij het filerijden (langzaamrijdend en/of stilstaand verkeer)?

Er zijn telkens vijf antwoordmogelijkheden:
1 = Veel behoefte aan
2 = Behoefte aan
3 = Misschien behoefte aan
4 = Geen behoefte aan
5 = Zeker geen behoefte aan

	Auto(snel)weg					Provinciale weg					Stad of dorp				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Waarschuwing bij onveilige afstand tot voorligger: overschrijding van zelfgekozen minimum volgafstand	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
De auto houdt automatisch veilige afstand tot voorligger, incl. optrekken, afremmen	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
De auto rijdt automatisch file, incl. binnen rijstrook blijven	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Misschien behoefte aan

Verder >

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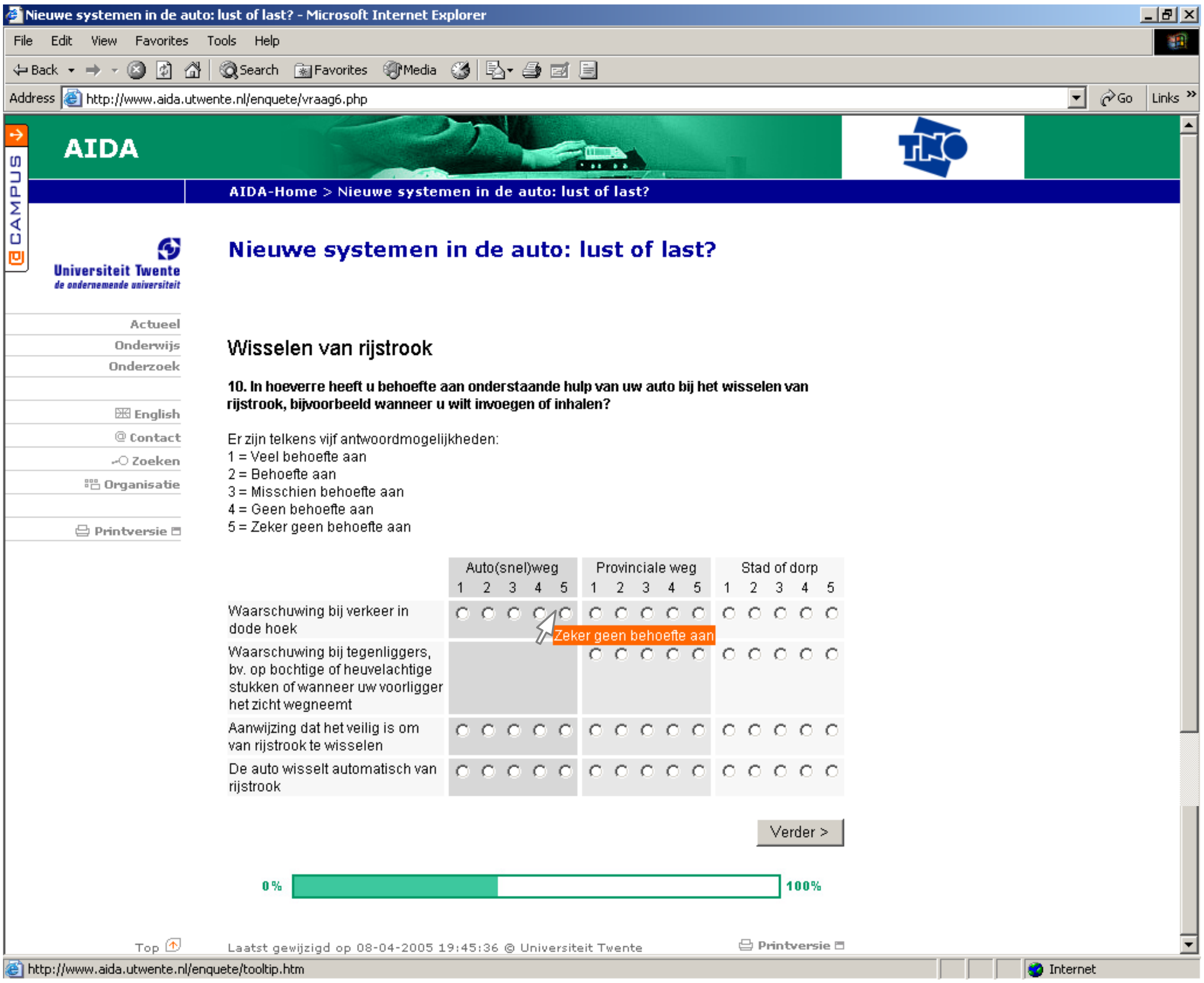

Nieuwe systemen in de auto: lust of last?

Wisselen van rijstrook

10. In hoeverre heeft u behoefte aan onderstaande hulp van uw auto bij het wisselen van rijstrook, bijvoorbeeld wanneer u wilt invoegen of inhalen?

Er zijn telkens vijf antwoordmogelijkheden:
1 = Veel behoefte aan
2 = Behoefte aan
3 = Misschien behoefte aan
4 = Geen behoefte aan
5 = Zeker geen behoefte aan

	Auto(snel)weg					Provinciale weg					Stad of dorp				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Waarschuwing bij verkeer in dode hoek	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Waarschuwing bij tegenliggers, bv. op bochtige of heuvelachtige stukken of wanneer uw voorligger het zicht wegneemt						○	○	○	○	○	○	○	○	○	○
Aanwijzing dat het veilig is om van rijstrook te wisselen	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
De auto wisselt automatisch van rijstrook	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Zeker geen behoefte aan

Verder >

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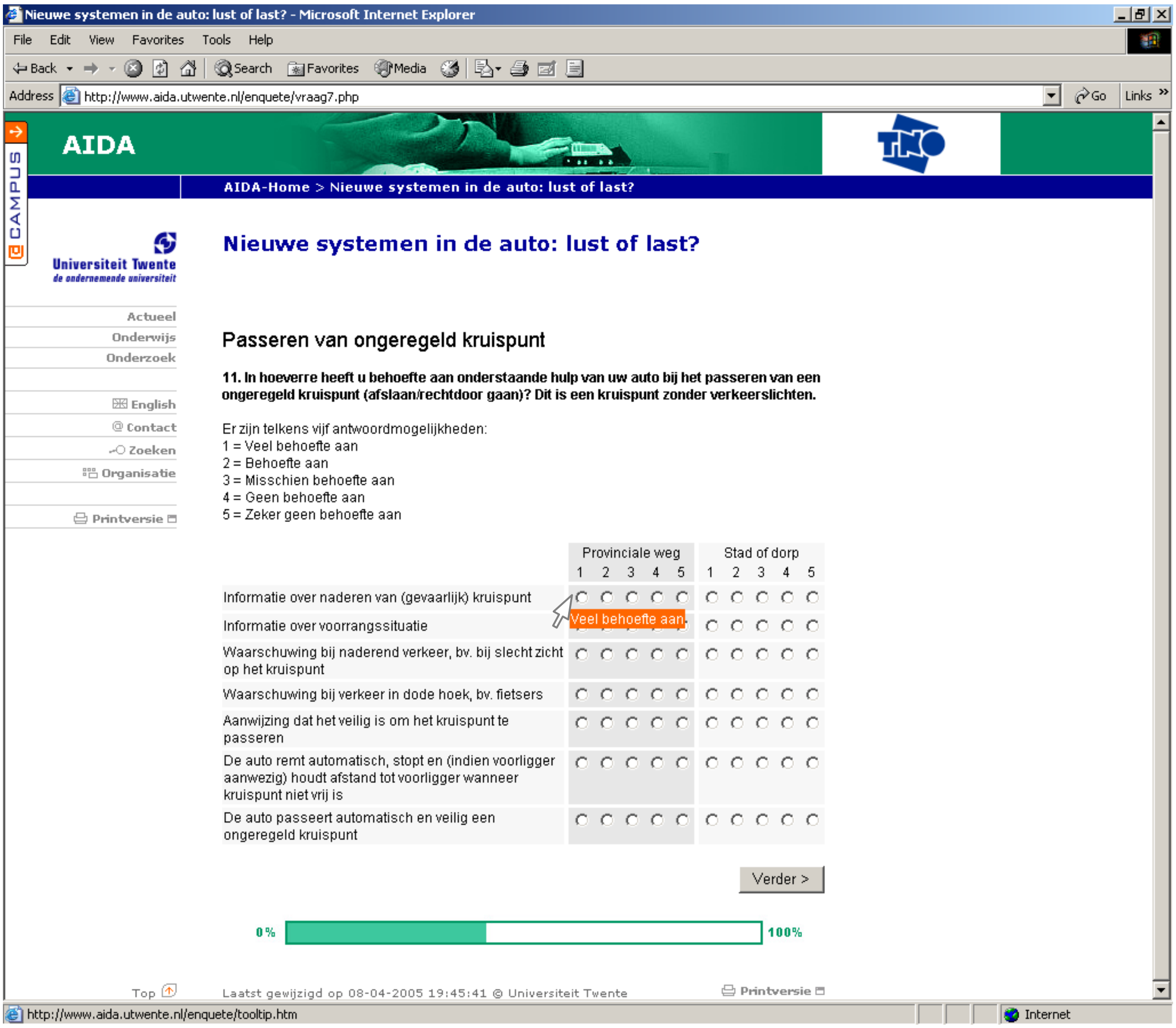

Nieuwe systemen in de auto: lust of last?

Passeren van ongeregeld kruispunt

11. In hoeverre heeft u behoefte aan onderstaande hulp van uw auto bij het passeren van een ongeregeld kruispunt (afslaan/rechtdoor gaan)? Dit is een kruispunt zonder verkeerslichten.

Er zijn telkens vijf antwoordmogelijkheden:
1 = Veel behoefte aan
2 = Behoefte aan
3 = Misschien behoefte aan
4 = Geen behoefte aan
5 = Zeker geen behoefte aan

	Provinciale weg					Stad of dorp				
	1	2	3	4	5	1	2	3	4	5
Informatie over naderen van (gevaarlijk) kruispunt	○	○	○	○	○	○	○	○	○	○
Informatie over voorrangssituatie	○	○	○	○	○	○	○	○	○	○
Waarschuwing bij naderend verkeer, bv. bij slecht zicht op het kruispunt	○	○	○	○	○	○	○	○	○	○
Waarschuwing bij verkeer in dode hoek, bv. fietsers	○	○	○	○	○	○	○	○	○	○
Aanwijzing dat het veilig is om het kruispunt te passeren	○	○	○	○	○	○	○	○	○	○
De auto remt automatisch, stopt en (indien voorligger aanwezig) houdt afstand tot voorligger wanneer kruispunt niet vrij is	○	○	○	○	○	○	○	○	○	○
De auto passeert automatisch en veilig een ongeregeld kruispunt	○	○	○	○	○	○	○	○	○	○

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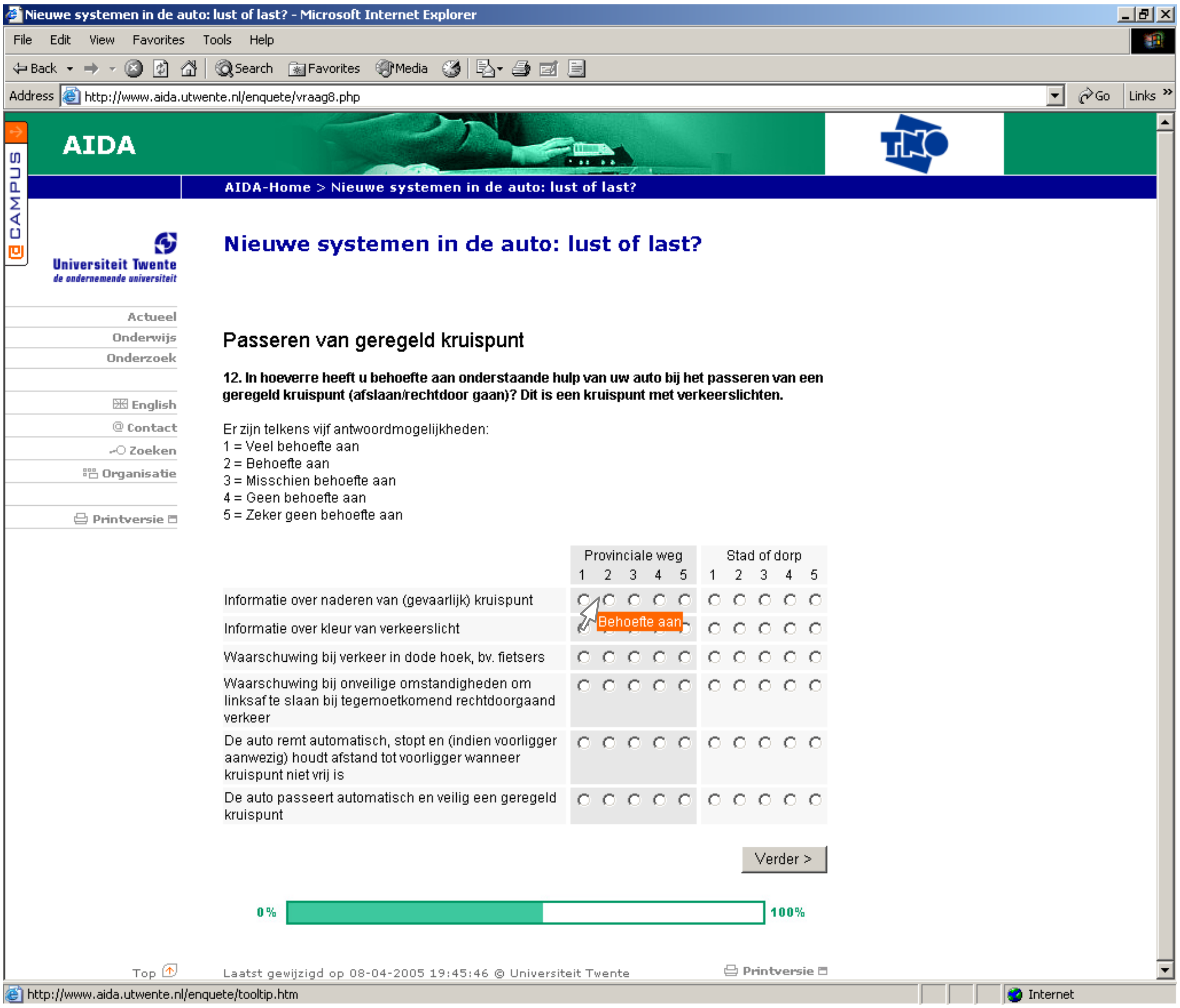

Nieuwe systemen in de auto: lust of last?

Passeren van geregeld kruispunt

12. In hoeverre heeft u behoefte aan onderstaande hulp van uw auto bij het passeren van een geregeld kruispunt (afslaan/rechtdoor gaan)? Dit is een kruispunt met verkeerslichten.

Er zijn telkens vijf antwoordmogelijkheden:
1 = Veel behoefte aan
2 = Behoefte aan
3 = Misschien behoefte aan
4 = Geen behoefte aan
5 = Zeker geen behoefte aan

	Provinciale weg					Stad of dorp				
	1	2	3	4	5	1	2	3	4	5
Informatie over naderen van (gevaarlijk) kruispunt	○	○	○	○	○	○	○	○	○	○
Informatie over kleur van verkeerslicht	○				○	○	○	○	○	○
Waarschuwing bij verkeer in dode hoek, bv. fietsers	○	○	○	○	○	○	○	○	○	○
Waarschuwing bij onveilige omstandigheden om linksaf te slaan bij tegemoetkomend rechtdoorgaand verkeer	○	○	○	○	○	○	○	○	○	○
De auto remt automatisch, stopt en (indien voorligger aanwezig) houdt afstand tot voorligger wanneer kruispunt niet vrij is	○	○	○	○	○	○	○	○	○	○
De auto passeert automatisch en veilig een geregeld kruispunt	○	○	○	○	○	○	○	○	○	○

Behoefte aan

Verder >

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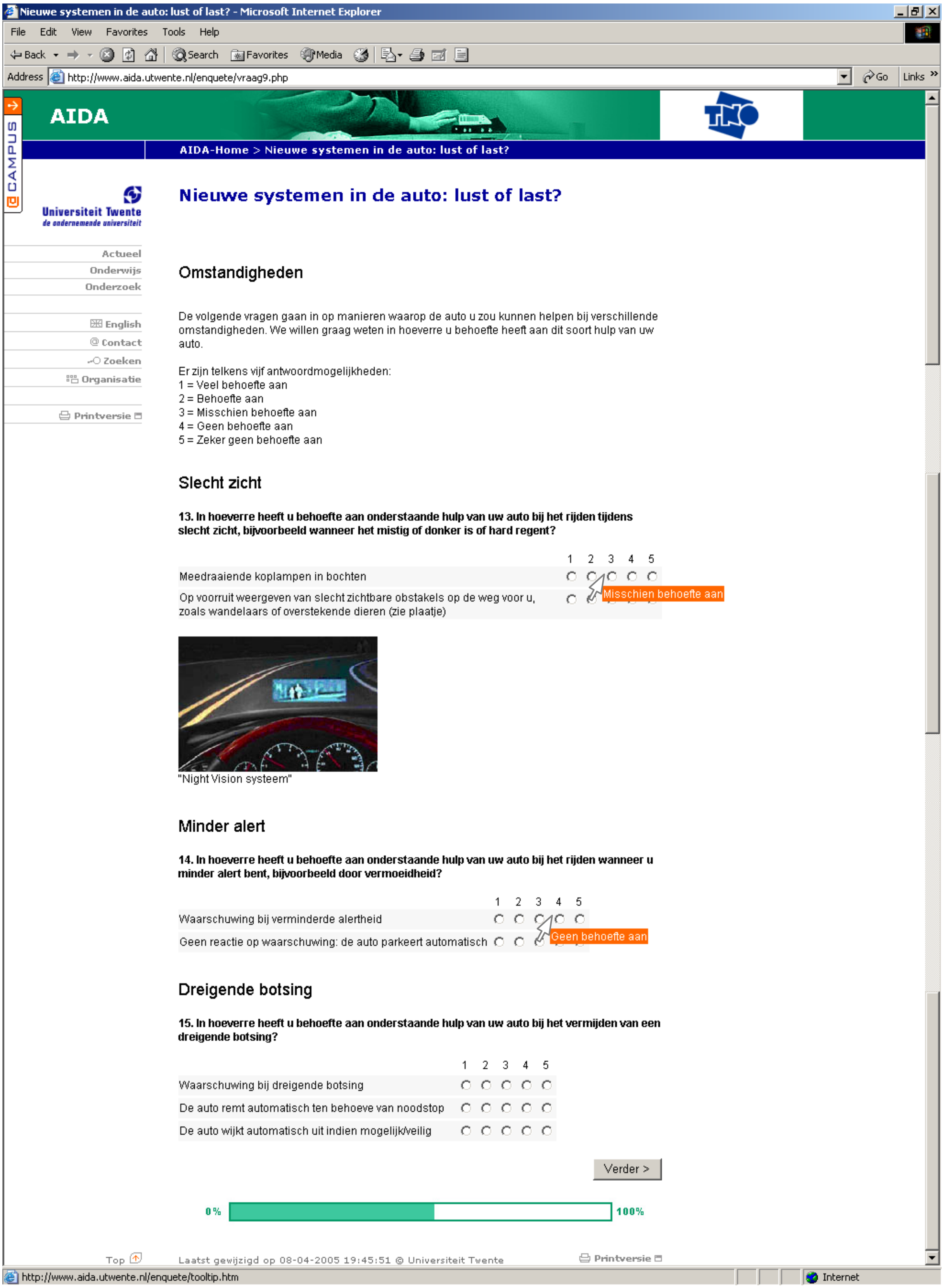

Nieuwe systemen in de auto: lust of last?

Omstandigheden

De volgende vragen gaan in op manieren waarop de auto u zou kunnen helpen bij verschillende omstandigheden. We willen graag weten in hoeverre u behoefte heeft aan dit soort hulp van uw auto.

Er zijn telkens vijf antwoordmogelijkheden:
1 = Veel behoefte aan
2 = Behoefte aan
3 = Misschien behoefte aan
4 = Geen behoefte aan
5 = Zeker geen behoefte aan

Slecht zicht

13. In hoeverre heeft u behoefte aan onderstaande hulp van uw auto bij het rijden tijdens slecht zicht, bijvoorbeeld wanneer het mistig of donker is of hard regent?

	1	2	3	4	5
Meedraaiende koplampen in bochten	○	○	○	○	○
Op voorruit weergeven van slecht zichtbare obstakels op de weg voor u, zoals wandelaars of overstekende dieren (zie plaatje)	○	○	○	○	○

Misschien behoefte aan

"Night Vision systeem"

Minder alert

14. In hoeverre heeft u behoefte aan onderstaande hulp van uw auto bij het rijden wanneer u minder alert bent, bijvoorbeeld door vermoeidheid?

	1	2	3	4	5
Waarschuwing bij verminderde alertheid	○	○	○	○	○
Geen reactie op waarschuwing: de auto parkeert automatisch	○	○	○	○	○

Geen behoefte aan

Dreigende botsing

15. In hoeverre heeft u behoefte aan onderstaande hulp van uw auto bij het vermijden van een dreigende botsing?

	1	2	3	4	5
Waarschuwing bij dreigende botsing	○	○	○	○	○
De auto remt automatisch ten behoeve van noodstop	○	○	○	○	○
De auto wijkt automatisch uit indien mogelijk/veilig	○	○	○	○	○

Verder >

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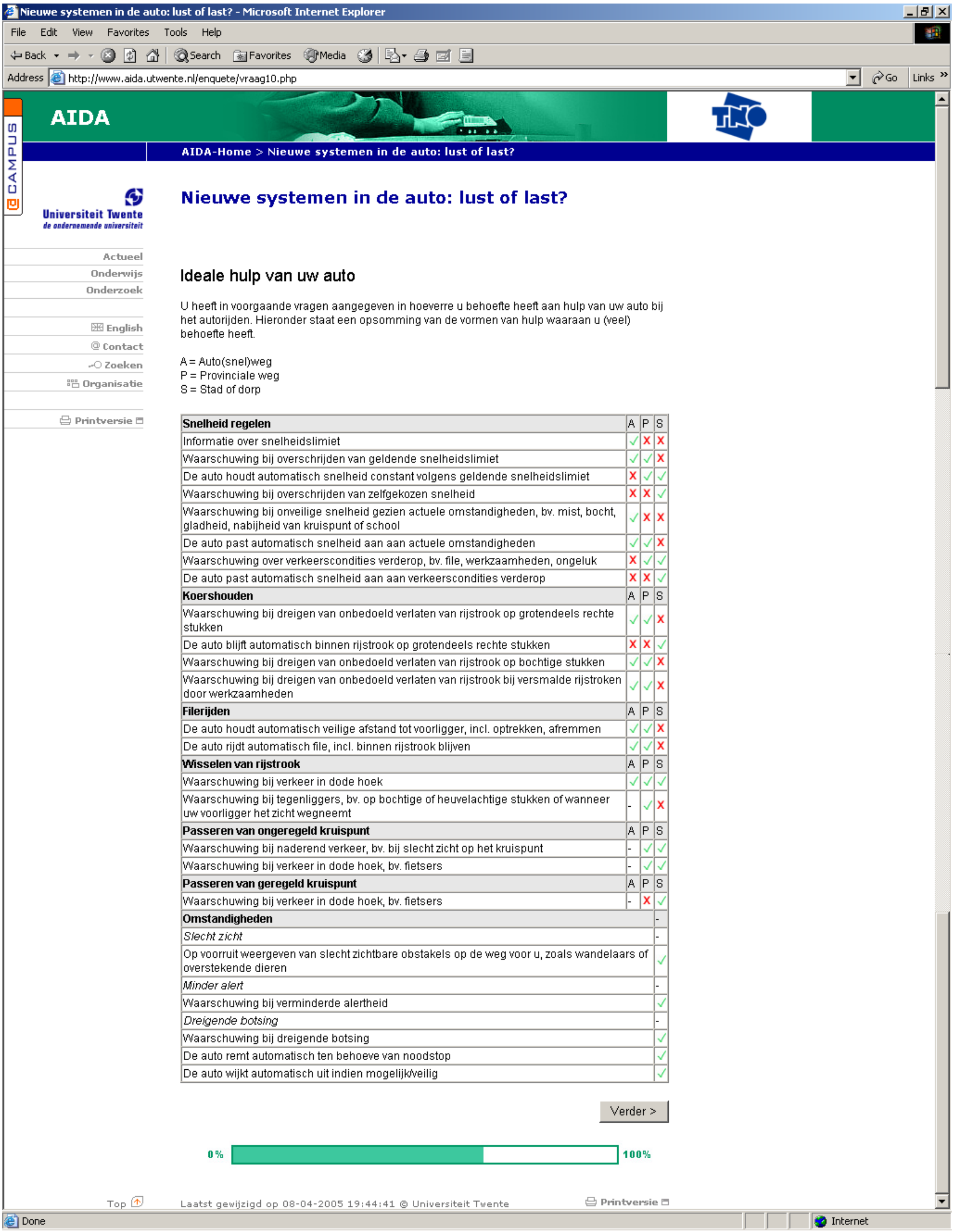
‘Personalized’ table with indicated needs for driver support functions based on the respondent’s previous answers



Nieuwe systemen in de auto: lust of last?

Ideale hulp van uw auto

U heeft in voorgaande vragen aangegeven in hoeverre u behoefte heeft aan hulp van uw auto bij het autorijden. Hieronder staat een opsomming van de vormen van hulp waaraan u (veel) behoefte heeft.

A = Auto(snel)weg
P = Provinciale weg
S = Stad of dorp

Snelheid regelen	A	P	S
Informatie over snelheidslimiet	✓	✗	✗
Waarschuwing bij overschrijden van geldende snelheidslimiet	✓	✓	✗
De auto houdt automatisch snelheid constant volgens geldende snelheidslimiet	✗	✓	✓
Waarschuwing bij overschrijden van zelfgekozen snelheid	✗	✗	✓
Waarschuwing bij onveilige snelheid gezien actuele omstandigheden, bv. mist, bocht, gladheid, nabijheid van kruispunt of school	✓	✗	✗
De auto past automatisch snelheid aan aan actuele omstandigheden	✓	✓	✗
Waarschuwing over verkeerscondities verderop, bv. file, werkzaamheden, ongeluk	✗	✓	✓
De auto past automatisch snelheid aan aan verkeerscondities verderop	✗	✗	✓
Koershouden	A	P	S
Waarschuwing bij dreigen van onbedoeld verlaten van rijstrook op grotendeels rechte stukken	✓	✓	✗
De auto blijft automatisch binnen rijstrook op grotendeels rechte stukken	✗	✗	✓
Waarschuwing bij dreigen van onbedoeld verlaten van rijstrook op bochtige stukken	✓	✓	✗
Waarschuwing bij dreigen van onbedoeld verlaten van rijstrook bij versmalde rijstroken door werkzaamheden	✓	✓	✗
Filerijden	A	P	S
De auto houdt automatisch veilige afstand tot voorligger, incl. optrekken, afremmen	✓	✓	✗
De auto rijdt automatisch file, incl. binnen rijstrook blijven	✓	✓	✗
Wisselen van rijstrook	A	P	S
Waarschuwing bij verkeer in dode hoek	✓	✓	✓
Waarschuwing bij tegenliggers, bv. op bochtige of heuvelachtige stukken of wanneer uw voorligger het zicht wegneemt	-	✓	✗
Passeren van ongeregeld kruispunt	A	P	S
Waarschuwing bij naderend verkeer, bv. bij slecht zicht op het kruispunt	-	✓	✓
Waarschuwing bij verkeer in dode hoek, bv. fietsers	-	✓	✓
Passeren van geregeld kruispunt	A	P	S
Waarschuwing bij verkeer in dode hoek, bv. fietsers	-	✗	✓
Omstandigheden			-
Slecht zicht			-
Op voorruit weergeven van slecht zichtbare obstakels op de weg voor u, zoals wandelaars of overstekende dieren			✓
Minder alert			-
Waarschuwing bij verminderde alertheid			✓
Dreigende botsing			-
Waarschuwing bij dreigende botsing			✓
De auto remt automatisch ten behoeve van noodstop			✓
De auto wijkt automatisch uit indien mogelijk/veilig			✓

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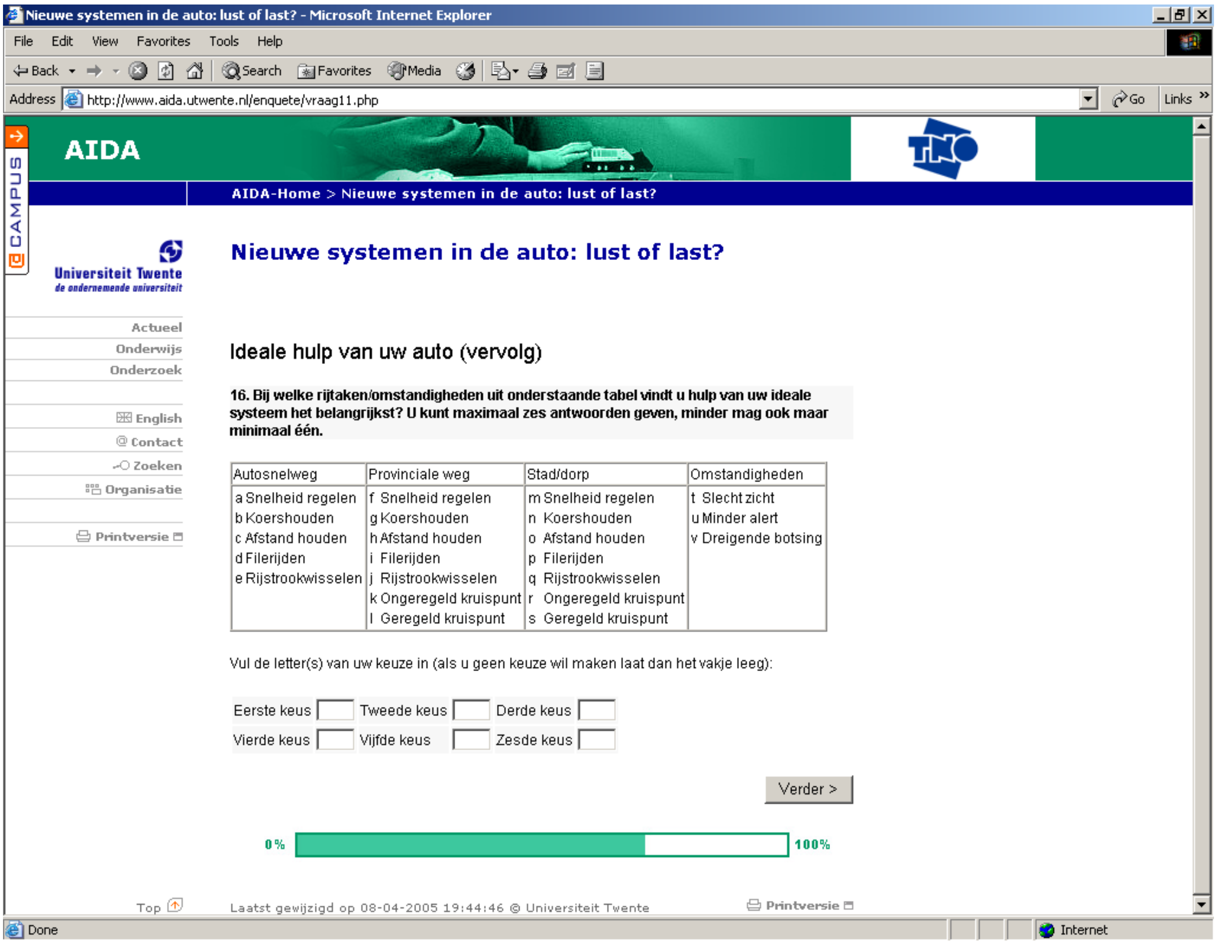
Questions about the ideal driver support system



Nieuwe systemen in de auto: lust of last?

Ideale hulp van uw auto (vervolg)

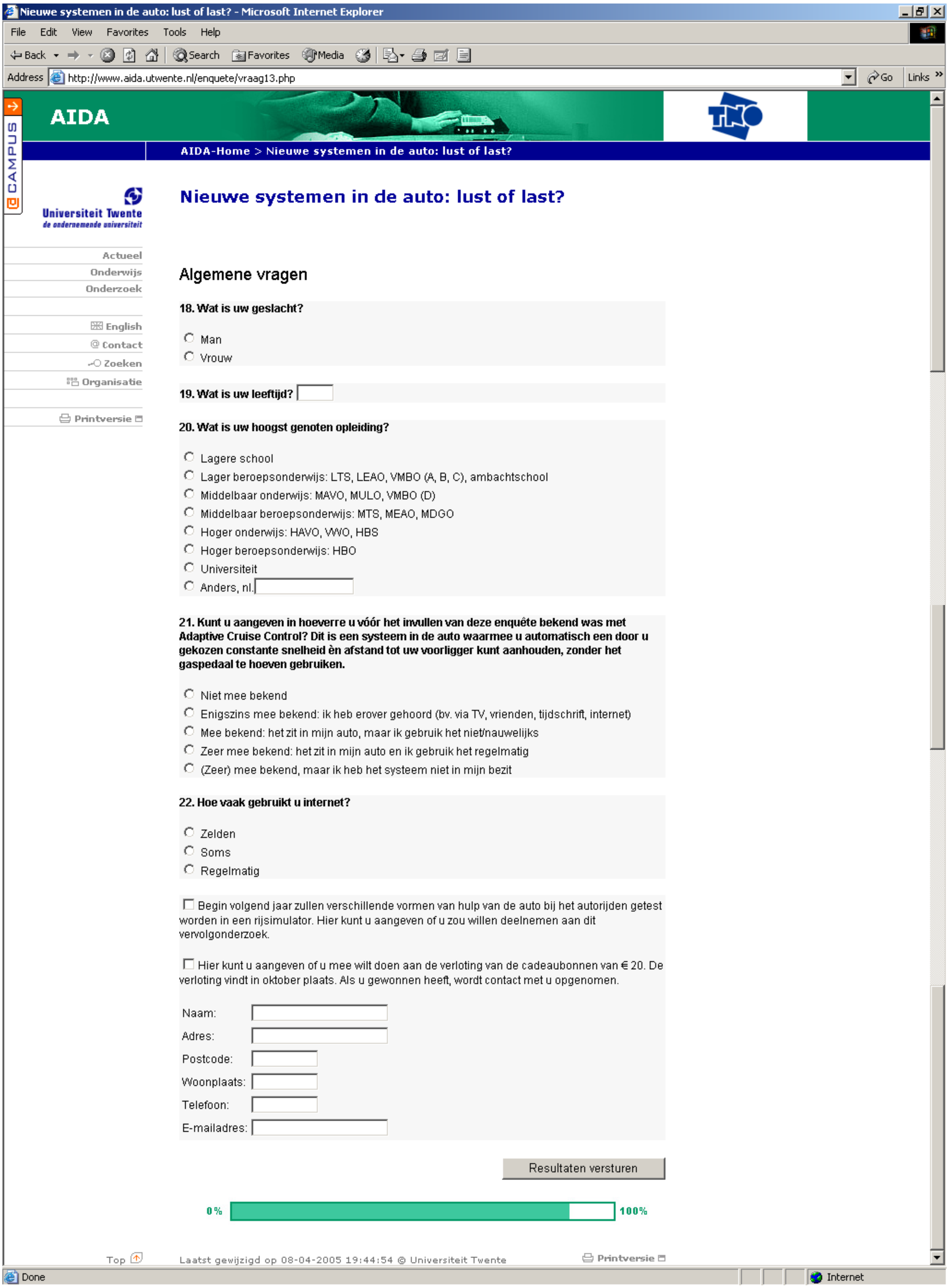
16. Bij welke rijtaken/omstandigheden uit onderstaande tabel vindt u hulp van uw ideale systeem het belangrijkst? U kunt maximaal zes antwoorden geven, minder mag ook maar minimaal één.

Autosnelweg	Provinciale weg	Stad/dorp	Omstandigheden
a Snelheid regelen	f Snelheid regelen	m Snelheid regelen	t Slecht zicht
b Koershouden	g Koershouden	n Koershouden	u Minder alert
c Afstand houden	h Afstand houden	o Afstand houden	v Dreigende botsing
d Filerijden	i Filerijden	p Filerijden	
e Rijstrookwisselen	j Rijstrookwisselen	q Rijstrookwisselen	
	k Ongeregeld kruispunt	r Ongeregeld kruispunt	
	l Geregeld kruispunt	s Geregeld kruispunt	

Vul de letter(s) van uw keuze in (als u geen keuze wil maken laat dan het vakje leeg):

Eerste keus	☐	Tweede keus	☐	Derde keus	☐
Vierde keus	☐	Vijfde keus	☐	Zesde keus	☐

Background questions, including a question about the willingness to participate in the follow-up of this user needs survey: a driving simulator experiment



Nieuwe systemen in de auto: lust of last?

Algemene vragen

18. Wat is uw geslacht?

○ Man
○ Vrouw

19. Wat is uw leeftijd? ____

20. Wat is uw hoogst genoten opleiding?

○ Lagere school
○ Lager beroepsonderwijs: LTS, LEAO, VMBO (A, B, C), ambachtschool
○ Middelbaar onderwijs: MAVO, MULO, VMBO (D)
○ Middelbaar beroepsonderwijs: MTS, MEAO, MDGO
○ Hoger onderwijs: HAVO, VWO, HBS
○ Hoger beroepsonderwijs: HBO
○ Universiteit
○ Anders, nl. ____

21. Kunt u aangeven in hoeverre u vóór het invullen van deze enquête bekend was met Adaptive Cruise Control? Dit is een systeem in de auto waarmee u automatisch een door u gekozen constante snelheid èn afstand tot uw voorligger kunt aanhouden, zonder het gaspedaal te hoeven gebruiken.

○ Niet mee bekend
○ Enigszins mee bekend: ik heb erover gehoord (bv. via TV, vrienden, tijdschrift, internet)
○ Mee bekend: het zit in mijn auto, maar ik gebruik het niet/nauwelijks
○ Zeer mee bekend: het zit in mijn auto en ik gebruik het regelmatig
○ (Zeer) mee bekend, maar ik heb het systeem niet in mijn bezit

22. Hoe vaak gebruikt u internet?

○ Zelden
○ Soms
○ Regelmatig

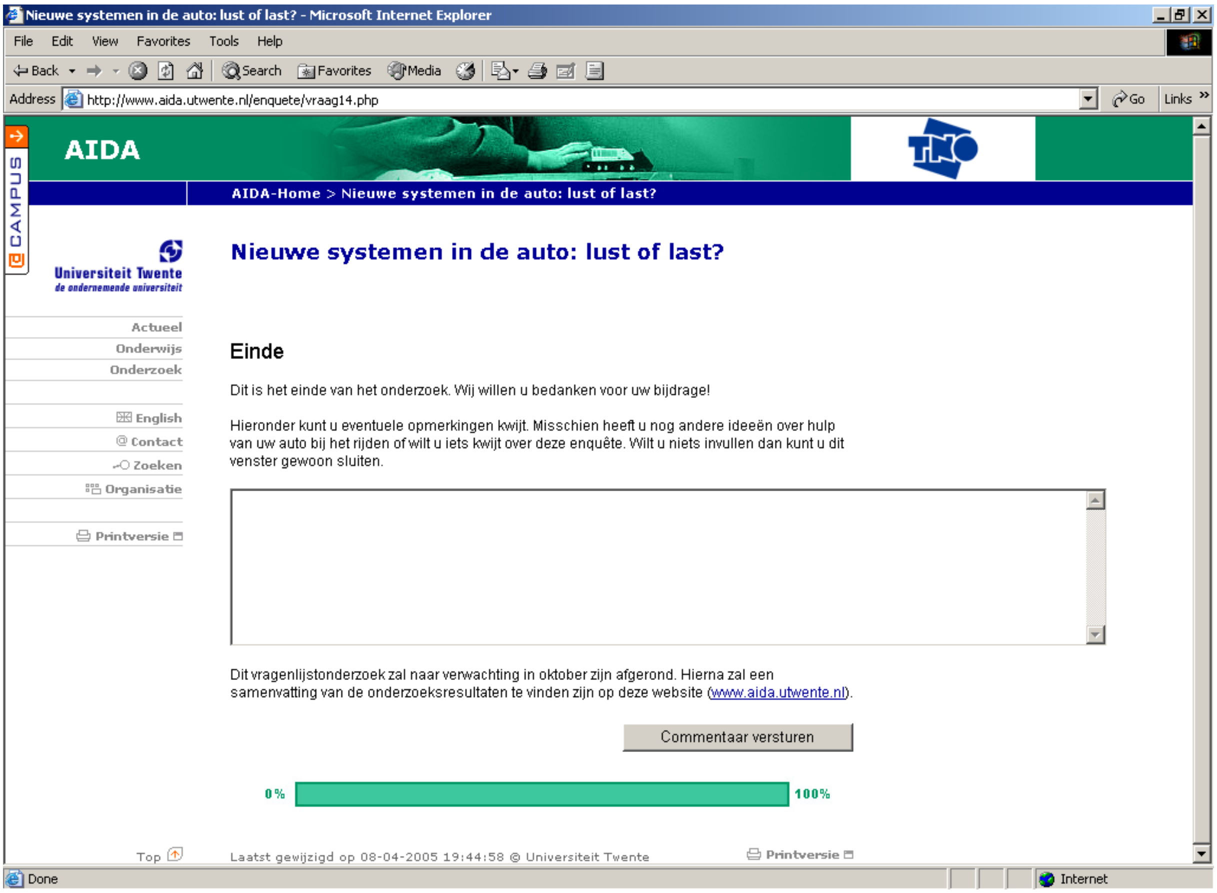
☐ Begin volgend jaar zullen verschillende vormen van hulp van de auto bij het autorijden getest worden in een rijsimulator. Hier kunt u aangeven of u zou willen deelnemen aan dit vervolgonderzoek.

☐ Hier kunt u aangeven of u mee wilt doen aan de verloting van de cadeaubonnen van € 20. De verloting vindt in oktober plaats. Als u gewonnen heeft, wordt contact met u opgenomen.

Naam: ____
Adres: ____
Postcode: ____
Woonplaats: ____
Telefoon: ____
E-mailadres: ____

Laatst gewijzigd op 08-04-2005 19:44:54 © Universiteit Twente

End of questionnaire with possibility for comments



Nieuwe systemen in de auto: lust of last?

Einde

Dit is het einde van het onderzoek. Wij willen u bedanken voor uw bijdrage!

Hieronder kunt u eventuele opmerkingen kwijt. Misschien heeft u nog andere ideeën over hulp van uw auto bij het rijden of wilt u iets kwijt over deze enquête. Wilt u niets invullen dan kunt u dit venster gewoon sluiten.

Dit vragenlijstonderzoek zal naar verwachting in oktober zijn afgerond. Hierna zal een samenvatting van de onderzoeksresultaten te vinden zijn op deze website (www.aida.utwente.nl).

Appendix B

McNemar test

This appendix presents more information about the McNemar test that was used to analyse the results from the user needs survey. McNemar tests were performed to distinguish between significantly greater needs for one thing (e.g. driver support function X) compared to another (e.g. driver support function Y). The following example illustrates the principle of this statistical test. The needs for warnings for downstream traffic conditions on motorways were compared to the needs for these warnings on rural roads. The five answer categories were split into ‘(great) need’ and ‘other’ (see table below).

Warning for downstream traffic conditions		**– rural road**	
		(great) need	*other*
– motorway	*(great) need*	881	65
	other	3	100

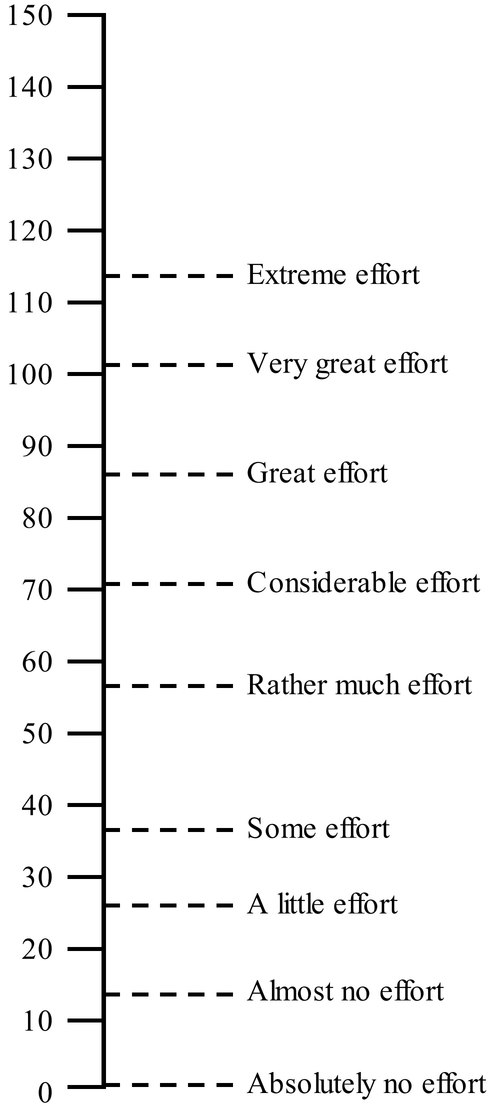
The McNemar test was used to test the hypothesis that the probabilities of the categories ‘(great) need’ and ‘other’ are the same for warnings for downstream traffic conditions on motorways and these warnings on rural roads. It is a non-parametric test for two related dichotomous variables using the chi-square distribution. The maximum likelihood estimates of the cell probabilities and the McNemar chi-square were computed using the two cells that correspond to ‘(great) need’ for only one of the two driver support functions. The test statistics for this example were $\chi^2 = 54.721$, with a corresponding p-value of 0.000. This means that the hypothesis was rejected in favour of the hypothesis that there was a significantly greater need for warnings for downstream traffic conditions on motorways than on rural roads. With this approach, all survey responses could be compared to each other. Because we did not examine all possible comparisons, a conservative p-level ($p<0.001$) was used to consider the results statistically significant.

Appendix C

Rating Scale Mental Effort

This appendix presents the Rating Scale Mental Effort (RSME). The participants had to fill in a Dutch version of this scale after each experimental run.

Instructions:
You have just driven with the Congestion Assistant during normal visibility. Please indicate, by marking the vertical axis below, how much effort this trip took you.



Appendix D

Acceptance questionnaire

This appendix shows the acceptance questionnaire. The participants had to fill in a Dutch version of this questionnaire before driving and after each experimental run with the Congestion Assistant: one questionnaire for the total system and one for each function of the system.

Instructions:
You are going to drive with the Congestion Assistant. First, you will receive a warning when there is a traffic jam ahead and you will receive information about the length of the jam when you are driving in it. Second, you will feel a counterforce of the gas pedal when you are approaching the traffic jam at too high speed. Third, the system will automatically accelerate and brake in the traffic jam.

My judgments of the total Congestion Assistant are ... (please tick a box on every line)

Useful						Useless
Pleasant						Unpleasant
Bad						Good
Nice						Annoying
Effective						Superfluous
Irritating						Likeable
Assisting						Worthless
Undesirable						Desirable
Raising alertness						Sleep-inducing

Appendix E

Juster scale

This appendix shows the purchase probability scale of Juster. The participants had to fill in a Dutch version of this scale after the experimental run with the Congestion Assistant during normal visibility.

Instructions:
You have just driven with the Congestion Assistant. First, you received a warning about the traffic jam ahead and you got information about the length of the jam when you were driving in it. Second, you felt a counterforce of the gas pedal when you were approaching the traffic jam at too high speed. Third, the system automatically accelerated and braked in the traffic jam.

Imagine that you buy a new car. What are the prospects that you will buy the Congestion Assistant priced €1500? Please circle the number (0-10) that corresponds to your opinion.

10	Certain, practically certain
9	Almost sure
8	Very probable
7	Probable
6	Good possibility
5	Fairly good possibility
4	Fair possibility
3	Some possibility
2	Slight possibility
1	Very slight possibility
0	No chance, almost no chance

Summary

Mobility is a key factor for modern societies. However, it also brings about problems, such as congestion, accidents and pollution. High expectations rest on in-vehicle systems to contribute to solving these problems. These so-called driver support systems use advanced information and communication technology to assist the driver in performing elements of the driving task, such as maintaining a proper speed or avoiding an accident. A variety of systems is under investigation or already commercially available. Most current systems are autonomous systems that do not communicate with other vehicles or the infrastructure. Recently, the development of driver support systems is more and more directed at cooperative systems that do communicate and therefore extend the driver's horizon. Despite the research and development efforts, the market introduction of driver support systems finds itself in an early stage. Car manufacturers employ a rather conservative strategy, because they are uncertain about the financial risks and the usability of these systems. Governments and road operators are uncertain about the actual impacts of driver support systems on traffic safety and traffic efficiency, which makes them hesitant to take measures to facilitate, stimulate or regulate the introduction of these systems. This thesis aims at reducing the above uncertainties by improving the knowledge of user needs for driver support systems and the impacts of one of such systems, the so-called Congestion Assistant, on the driver and the traffic flow.

The success of driver support systems is highly dependent on the willingness of the end users, that are the drivers, to have and use these systems. So it is essential to know to what extent drivers would like to be assisted by their cars when driving. Therefore, a user needs survey was conducted to investigate the perceived needs for driver assistance. This survey focused on support with several driving tasks and situations, which is in contrast to earlier research that generally concentrated on 'ready to use' systems, such as Adaptive Cruise Control. A total of 1049 Dutch car drivers completed the survey on the Internet. It appeared that warnings for downstream traffic conditions and warnings for traffic in blind spots were favoured. Apparently, drivers appreciate being well informed when driving. Automatic actions from the car were not rated highly, except for taking over the driving task in congestion. Furthermore,

the respondents preferred the ideal system to give support in critical situations, such as an imminent crash or reduced visibility. These needs have implications for the design of driver support systems. One can expect that the integration of functions is sensible, for example by exchanging information between vehicles and using one user interface.

The results from the user needs survey also revealed a significant need for several forms of congestion assistance. Based on these preferences, the Congestion Assistant was developed. This in-vehicle system consists of a mix of informing, assisting and controlling functions and supports the driver during congested traffic situations on motorways:

- Warning & Information: the driver receives warnings about a traffic jam ahead and information about the length of the jam when driving in it.
- Active pedal: the driver feels a counterforce of the gas pedal when approaching the jam at too high speed.
- Stop & Go: the system takes over the longitudinal driving task from the driver when driving in the jam.

Changes in driving behaviour due to driver support systems determine how useful and effective these systems are. So it is necessary to know to what extent drivers are able and willing to interact with a system. Therefore, a driving simulator experiment was conducted to investigate the impacts of the Congestion Assistant on the driver. A total of 37 participants gained experience with the Congestion Assistant in the driving simulator during normal view and fog conditions. These participants were selected from the respondents to the user needs survey. Their acceptance of the Congestion Assistant appeared to be related to their perceived needs for congestion assistance. It was therefore concluded that the user needs survey can be seen as a valid method for the indication of driver needs for congestion assistance.

The assessment of the Congestion Assistant in the driving simulator experiment focused on driving behaviour, mental workload and acceptance. The Warning function was not found to affect driving behaviour. The Active pedal caused earlier speed adaptations and safer car-following behaviour when approaching the traffic jam, which shows indications of an improved traffic safety. The Stop & Go resulted in ‘smoother driving’ with smaller time headways in the traffic jam, which is expected to enhance traffic efficiency. The participants experienced a lower mental workload with the Congestion Assistant, but only when driving in fog. The mental workload was higher when one approached the traffic jam with the Active pedal. This could be due to an increase in the driver’s attention to the upcoming jam or to the pedal itself giving a ‘sudden’ counterforce. Driving with the Stop & Go resulted in a lower mental workload. This might decrease the driver’s alertness. In general, the participants stated that they appreciated the Congestion Assistant and were willing to buy the system. Particularly the Warning & Information and the Stop & Go were favoured. The acceptance of the Stop & Go significantly increased after having gained experience with it. The participants were less enthusiastic about the Active pedal.

Individual driving behaviour determines to a large extent how efficient and safe the traffic flow behaves. So it is important to understand the significance of a change in driving behaviour of individual drivers due to driver support systems in relation to the performance of a whole traffic flow. Therefore, a microscopic traffic simulation study was conducted to investigate the impacts of the Congestion Assistant on the traffic flow. The Congestion Assistant in this study included either the Active pedal or the Stop & Go or a combination of both functions. The traffic flow impacts of six variants of the system were analysed at two equipment rates. The simulated road consisted of a four-lane motorway segment with a left lane drop that caused congestion. The traffic flow model applied in this research was extended to include vehicles equipped with the Congestion Assistant. Data collected on the Dutch A12 motorway were used to validate and calibrate the reference situation in which no vehicles were equipped with the system. The simulation results showed a satisfactory resemblance with respect to the congestion build-up. The calibration process led to more insight into the trade-off between the parameter settings on the one hand and the onset and course of congestion on the other hand.

The assessment of the Congestion Assistant in the traffic simulation study focused on traffic efficiency and traffic safety. All variants of the Congestion Assistant resulted in less congestion in comparison with the reference situation. The higher the equipment rate of the Congestion Assistant, the larger were these positive effects. The Active pedal smoothed the traffic flow when approaching the traffic jam by inducing better anticipation behaviour of the driver compared to unsupported drivers. This had a small effect on the dissipation of congestion, rather it affected traffic safety by a safer approach to the jam. Vehicles equipped with the Stop & Go followed other vehicles more efficiently than non-equipped vehicles when driving in and leaving a jam by maintaining smaller headways and eliminating the reaction time of drivers. This reduced the amount of congestion significantly. At the same time, this function also increased the amount of hard braking. Adapting the acceleration algorithm of the Stop & Go will presumably compensate for this effect. The Active pedal showed no added value with respect to traffic efficiency when it was combined with the Stop & Go. But the combination of these two functions decreased the percentages of hard braking and small Time-To-Collision* values, although these percentages were lowest for the Congestion Assistant consisting of only the Active pedal.

In conclusion, this thesis provides more insight into the user needs for driver assistance and the impacts of the Congestion Assistant on the driver and the traffic flow. The promising results found in this research project give rise to speeding up the further development of the Congestion Assistant. The Warning function and the Active pedal are assumed to have knowledge of what is happening further down the road. Such cooperative applications will probably become available after 2010. Until then, the efforts should also be concentrated on autonomous applications, such as the Stop & Go. For the automotive industry, it is relevant to know that people are willing to hand over the driving task in congestion to their cars. For public authorities, it is important to realize that the Stop & Go has promising impacts on the dissipation of traffic jams. In view of the severe congestion problems in Europe, it is recommended that both parties work together and in the short run come to a system that serves all interests, including those of the driver, best.

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* Time-To-Collision: the time required for two vehicles to collide if they continue at their present speed and on the same path.

Samenvatting

Mobiliteit is onmisbaar in een moderne samenleving. Het zorgt echter ook voor problemen, zoals congestie, onveiligheid en luchtvervuiling. De toepassing van in-car systemen wordt gezien als een mogelijkheid om deze problemen tegen te gaan. Deze systemen – ook wel bestuurdersondersteunende systemen genoemd – gebruiken geavanceerde informatie- en communicatietechnologie om de bestuurder te helpen bij het uitvoeren van zijn rijtaak, zoals het rijden met gepaste snelheid of het vermijden van een botsing. Er wordt onderzoek gedaan naar een verscheidenheid aan systemen, waarvan enkele al op de markt verkrijgbaar zijn. De meeste huidige systemen zijn autonome systemen die niet communiceren met andere voertuigen of de infrastructuur. Recentelijk wordt meer aandacht besteed aan het ontwikkelen van coöperatieve systemen die wel communiceren en op die manier het blikveld van de bestuurder kunnen vergroten. Ondanks de inspanningen op het gebied van onderzoek en ontwikkeling verloopt de marktinvoering van bestuurdersondersteunende systemen traag. Autofabrikanten hanteren een nogal conservatieve strategie, omdat ze onzeker zijn over de financiële risico’s en het nut van dit soort systemen. Overheden en wegbeheerders zijn onzeker over de werkelijke effecten van bestuurdersondersteunende systemen op verkeersveiligheid en doorstroming, waardoor ze aarzelen over het nemen van maatregelen om de introductie van dit soort systemen te faciliteren, stimuleren of reguleren. Dit proefschrift probeert bovenstaande onzekerheden weg te nemen door het verschaffen van meer kennis over de gebruikersbehoeften aan bestuurdersondersteunende systemen en de effecten van zo’n systeem, de zogenaamde Fileassistent, op de bestuurder en de verkeersstroom.

Het succes van bestuurdersondersteunende systemen is grotendeels afhankelijk van de bereidheid van de eindgebruikers, oftewel de bestuurders, om zulke systemen te hebben en te gebruiken. Daarom is het belangrijk om te weten in hoeverre bestuurders tijdens het rijden ondersteund zouden willen worden door hun auto. Door middel van een vragenlijstonderzoek zijn de gebruikersbehoeften aan bestuurdersondersteuning onderzocht. De enquête richtte zich op hulp bij verschillende rijtaken en omstandigheden, in tegenstelling tot eerder onderzoek dat met name gericht was op ‘kant-en-klare’ systemen, zoals Adaptive Cruise Control. De internetenquête werd door 1049 Nederlandse automobilisten ingevuld. Men bleek vooral behoefte te hebben aan waarschuwingen over de verkeerscondities verderop en waarschuwingen voor verkeer in de dode hoek. Blijkbaar willen bestuurders graag goed geïnformeerd zijn tijdens het rijden. Automatische acties van de auto werden niet erg gewaardeerd, behalve als het gaat om het overnemen van de rijtaak in de file. Daarnaast gaven de respondenten aan dat het ideale systeem hulp zou moeten bieden in kritieke situaties, zoals een dreigende botsing of verminderd zicht. Deze gebruikersbehoeften hebben implicaties voor het ontwerpen van bestuurdersondersteunende systemen. Zo kan het verstandig zijn om functies te integreren, bijvoorbeeld met betrekking tot het uitwisselen van informatie tussen voertuigen of het ontwikkelen van één gebruikersinterface.

De resultaten van het vragenlijstonderzoek lieten ook een significante behoefte zien aan verschillende vormen van bestuurdersondersteuning tijdens fileomstandigheden. Gebaseerd op deze voorkeuren is de Fileassistent ontwikkeld. Dit in-car systeem bestaat uit een combinatie van informerende, assisterende en overnemende functies en helpt de bestuurder tijdens fileomstandigheden op de snelweg:

- Filewaarschuwing en -informatie: de bestuurder ontvangt waarschuwingen als er verderop file staat en ontvangt informatie tijdens het rijden in de file.
- Actief gaspedaal: de bestuurder voelt een tegendruk op het gaspedaal als hij met een te hoge snelheid op de file afrijdt.
- Stop & Go: het systeem neemt tijdens het rijden in de file de longitudinale rijtaak over van de bestuurder.

Veranderingen in rijgedrag als gevolg van bestuurdersondersteunende systemen bepalen de bruikbaarheid en effectiviteit van deze systemen. Daarom is het noodzakelijk om te weten in hoeverre bestuurders kunnen en willen rijden met een dergelijk systeem. Om de effecten van de Fileassistent op de bestuurder te onderzoeken is een rijsimulatorexperiment uitgevoerd. Een groep van 37 proefpersonen heeft in de rijsimulator ervaring opgedaan met de Fileassistent tijdens normaal zicht en mistomstandigheden. Deze proefpersonen werden geselecteerd uit de respondenten van het vragenlijstonderzoek. Hun acceptatie van de Fileassistent bleek samen te hangen met hun behoeften aan filehulp. Op grond hiervan is geconcludeerd dat de enquête een valide middel is om de gebruikersbehoeften aan filehulp te identificeren.

De evaluatie van de Fileassistent in het rijsimulatorexperiment richtte zich op rijgedrag, mentale werkbelasting en acceptatie. De Filewaarschuwing bleek geen invloed te hebben op het rijgedrag. Het Actieve gaspedaal zorgde voor eerdere snelheidsaanpassingen en veiliger volggedrag bij het naderen van de file, wat indicaties zijn voor een verbeterde verkeersveiligheid. De Stop & Go resulteerde in gelijkmatiger rijgedrag met kleinere volgtijden tijdens het rijden in de file. Hiervan wordt verwacht dat het de doorstroming bevordert. De proefpersonen ondervonden een lagere mentale werkbelasting met de Fileassistent, maar alleen gedurende mistomstandigheden. De mentale werkbelasting was hoger wanneer men de file naderde met het Actieve gaspedaal. Dit zou verklaard kunnen worden door de verhoogde alertheid van de bestuurder met betrekking tot de naderende file of door het pedaal zelf dat ‘plotseling’ tegendruk geeft. Het rijden met de Stop & Go resulteerde in een lagere werkbelasting. Dit zou kunnen leiden tot een verminderde alertheid van de bestuurder. Over het algemeen waardeerden de proefpersonen de Fileassistent en waren ze bereid het systeem aan te schaffen. Men stond met name positief tegenover de Filewaarschuwing en -informatie en de Stop & Go. De acceptatie van de Stop & Go nam significant toe nadat bestuurders ermee gereden hadden. De proefpersonen waren minder enthousiast over het Actieve gaspedaal.

De efficiëntie en veiligheid van een verkeersstroom wordt in grote mate bepaald door individueel rijgedrag. Om die reden is het belangrijk om veranderingen in individueel rijgedrag als gevolg van bestuurdersondersteunende systemen in verband te brengen met de prestatie van een verkeersstroom. Door middel van een microscopische verkeerssimulatiestudie zijn de effecten van de Fileassistent op de verkeersstroom onderzocht. De Fileassistent bestond in deze studie uit het Actieve gaspedaal, de Stop & Go of beide. Zes varianten van het systeem met twee uitrustingsgraden zijn geanalyseerd op hun verkeersstroomeffecten. De gesimuleerde weg omvatte een segment van een vierstrooks autosnelweg met een rijstrookvermindering waardoor congestie optrad. Het gebruikte verkeersmodel is uitgebreid om voertuigen met de Fileassistent te modelleren. De referentiesituatie waarin zonder Fileassistent gereden werd is gevalideerd en gecalibreerd met data die verzameld zijn op de Nederlandse autosnelweg A12. De fileopbouw in de simulatie vertoonde goede overeenkomsten met de A12-data. Het calibratieproces vergrootte het inzicht in de invloed van enkele parameters op het begin en het verloop van de file.

De evaluatie van de Fileassistent in de verkeerssimulatiestudie richtte zich op doorstroming en verkeersveiligheid. Alle varianten van de Fileassistent resulteerden in minder congestie vergeleken met de referentiesituatie. Hoe hoger de uitrustingsgraad, hoe groter de positieve effecten. Tijdens het naderen van de file zorgde het Actieve gaspedaal voor een gelijkmatiger verkeersstroom, omdat deze bestuurders beter anticipeerden dan de bestuurders zonder systeem. Dit had een klein effect op het oplossen van de file. De verkeersveiligheid daarentegen nam toe, omdat men de file veiliger naderde. Tijdens het rijden in de file en het verlaten van de file volgden voertuigen met de Stop & Go het andere verkeer efficiënter dan voertuigen zonder de Stop & Go. De hoeveelheid congestie verminderde aanzienlijk, omdat de Stop & Go kortere volgtijden hanteerde en de reactietijd van bestuurders elimineerde. De Stop & Go zorgde echter ook voor meer harde remacties. Dit kan waarschijnlijk gereduceerd worden door het acceleratiealgoritme van de Stop & Go aan te passen. Het Actieve gaspedaal had in combinatie met de Stop & Go geen toegevoegde waarde met betrekking tot de doorstroming. Echter, de combinatie van deze twee functies resulteerde in lagere percentages harde remacties en kleine Time-To-Collision* waarden, hoewel deze percentages het laagst waren voor de Fileassistent met alleen het Actieve gaspedaal.

Samenvattend, dit proefschrift verschaft meer inzicht in de gebruikersbehoeften voor bestuurdersondersteuning en de effecten van de Fileassistent op de bestuurder en de verkeersstroom. De veelbelovende resultaten uit dit onderzoek geven aanleiding tot het versnellen van de verdere ontwikkeling van de Fileassistent. De Filewaarschuwing en het Actieve gaspedaal worden verondersteld te weten wat er stroomafwaarts op de weg gebeurt. Zulke coöperatieve toepassingen zullen waarschijnlijk beschikbaar komen na 2010. Tot die tijd zou de ontwikkeling zich ook moeten richten op autonome toepassingen, zoals de Stop & Go. Voor de autoindustrie is het relevant te weten dat mensen bereid zijn de rijtaak in de file over te dragen aan hun auto. Voor de overheid is het belangrijk om zich te realiseren dat de Stop & Go veelbelovende effecten heeft op het oplossen van congestie. Met het oog op de ernstige congestieproblemen in Europa is het aan te raden dat beide partijen samenwerken en op de korte termijn komen tot een systeem dat alle belangen behartigt, met name die van de bestuurder.

* Time-To-Collision: de tijd die nog resteert tot twee voertuigen zullen botsen als koers en snelheid ongewijzigd blijven.

Dankwoord

Terwijl ik in Basel langzaam gewend raak aan het Zwitserse leven, denk ik vandaag terug aan de mensen die een bijdrage hebben geleverd aan mijn promotieonderzoek, in welke mate of vorm dan ook. Deze mensen wil ik graag noemen in dit dankwoord.

Als eerste wil ik mijn promotor Bart van Arem bedanken. Bart, bedankt voor het vertrouwen dat je in mij gehad hebt, al vanaf het eerste kopje koffie! Je was altijd enthousiast en positief, zelfs op de momenten dat ik het onderzoek niet meer zag zitten. Daarnaast heb je mij doen inzien dat er naast de wetenschappelijke kant van onderzoek ook aandacht moet zijn voor de toepassing en het management ervan. Verder wil ik mijn afdelingshoofd Martin van Maarseveen bedanken. Martin, voorbestemd of niet, jij hebt me in dienst genomen en ik ben blij dat ik de afgelopen jaren deel uitmaakte van jouw afdeling. De samenwerking met TNO binnen het kenniscentrum AIDA heb ik als erg plezierig ervaren. In het kader hiervan ben ik vooral Marika Hoedemaeker en Tanja Vonk dank verschuldigd. Marika, ik heb veel van je geleerd met betrekking tot het doen van rijsimulatoronderzoek en vind het een eer dat je in mijn promotiecommissie zit. Tanja, jouw frisse blik op mijn onderzoek vond ik erg waardevol. Ik wil jullie allebei bedanken voor het doornemen van mijn concept-proefschrift. Jullie aandeel in het eindresultaat is aanzienlijk!

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About the author

Cornelie van Driel was born on 20 November 1977 in Tiel, The Netherlands. She started her academic education in Civil Engineering & Management at the University of Twente in 1995. Cornelie specialized in traffic and transport and followed some additional courses on psychology and marketing. Her internship was conducted at Amsterdam Airport Schiphol where she analysed road accident data and made recommendations to enhance traffic safety. Cornelie obtained her Master's degree in 2001. Her Master's research focused on the effects of an edgeline on speed and lateral position using a meta-analytic approach. This research was carried out at the Institute for Road Safety Research (SWOV) in The Netherlands.

In October 2001 Cornelie joined the Centre for Transport Studies of the University of Twente as a researcher. She worked on the specification and evaluation of the Modern Drive Device, an in-vehicle system that aims at economical driving. In addition she wrote a proposal for the PhD study that is described in this thesis. In April 2003 she started her PhD study at the University of Twente in cooperation with the Netherlands Organisation for Applied Scientific Research (TNO) within the framework of knowledge centre Applications of Integrated Driver Assistance (AIDA). Besides doing her PhD research, she conducted PR activities for AIDA, supervised students and reviewed international conference and journal papers.

At present Cornelie lives together with her partner Steffen in Basel, Switzerland, and is looking for a job. Her main interest involves studying aspects of the way humans relate to the technical and social world around them, for example in the areas of driver support systems and traffic safety.

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