7. Advanced driver assistance systems that fit the needs of the older driver

Based on the earlier identified weaknesses and their relevance to road safety, it was concluded that to have the most potential to improve the road safety of older drivers, advanced driver assistance systems (ADAS) should: a) draw attention to approaching traffic, b) signal road users located in the driver’s blind spot, c) assist the driver in directing his attention to relevant information, and/or d) provide prior knowledge on the next traffic situation. Systems that appear to provide one or more of these kinds of support are: 1) collision warning systems aimed at intersections, 2) automated lane changing and merging systems, 3) reversing aids, 4) in-vehicle signing systems, 5) intelligent cruise control, and 6) a system that gives information on the characteristics of complex intersections the driver is about to cross. This chapter describes these systems based on what they do, what their advantages and disadvantages are, whether they are already on the market, whether they have been tested by older drivers, and if so, what effects the systems had on driving behaviour. In addition, it discusses what the preconditions are for these ADAS to actually improve road safety. It is concluded that conclusions cannot be drawn yet about whether certain ADAS can improve the safety of older drivers. Although systems have been developed that appear to fit the needs of the older driver, many are still being developed and not much research has been done on user acceptance and the effects on road user behaviour.

7.1. Introduction

Starting from the needs for support that were identified at the end of Chapter 4, this chapter discusses advanced driver assistance systems (ADAS) that may be able to provide the desired types of support. As the needs for support were based on the functional limitations of older people and their relevance to road safety, driver assistance systems that provide the desired types of support are considered to be the systems that have the most potential to improve the safety of older drivers. Section 7.2 discusses these systems.

The mere fact that an advanced driver assistance system provides one or more of the desired types of support is, however, not enough to actually improve the safety of the older driver. Other aspects of the assistance system,

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7 This chapter was based on chapter 4 of SWOV report R-2003-30 (Davidse, 2004a). Various parts of this chapter were published in IATSS Research, 30(10), 6-20 (Davidse, 2006), and presented at the first HUMANIST conference on driver needs (Davidse, 2004b) and at the International Conference on Transport and Traffic Psychology ICTTP in Nottingham (UK) (Davidse, 2004c).
such as user acceptance and design of the human machine interface are equally important. These aspects are dealt with in Section 7.3.

This chapter closes of with an evaluation of the merits and demerits of currently available ADAS as means to improve the safety of older drivers (Section 7.4).

7.2. Evaluation of ADAS

Several studies have mentioned ADAS that might be able to provide tailored assistance for older drivers (see for example Bekiaris, 1999; Färber, 2000; Mitchell & Suen, 1997; Shaheen & Niemeier, 2001). In this section, the focus will be on those ADAS that fit the needs as identified in Section 4.6. The desired functionalities that were listed in that section are summarized in Table 7.1, followed by the driver assistance systems that appear to incorporate them. In the next paragraphs, each of these systems will be described based on what they do, what their pros and cons are, whether they are already on the market, whether they have been tested by older drivers, and if so what the results of these tests were8.

<table>
<thead>
<tr>
<th>Desired functionality</th>
<th>ADAS</th>
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</thead>
<tbody>
<tr>
<td>Draw attention to approaching traffic</td>
<td>- Collision warning systems aimed at intersections</td>
</tr>
<tr>
<td></td>
<td>- Automated lane changing and merging systems</td>
</tr>
<tr>
<td>Signal road users located in the driver’s blind spot</td>
<td>- Automated lane changing and merging systems</td>
</tr>
<tr>
<td></td>
<td>- Blind spot and obstacle detection systems</td>
</tr>
<tr>
<td>Assist the driver in directing his attention to relevant information</td>
<td>- In-vehicle signing systems</td>
</tr>
<tr>
<td></td>
<td>- Special intelligent cruise control</td>
</tr>
<tr>
<td>Provide prior knowledge on the next traffic situation</td>
<td>- Systems that give information on the characteristics of complex intersections the driver is about to cross</td>
</tr>
</tbody>
</table>

Table 7.1. Desired functionalities and ADAS that appear to offer them (adapted from Mitchell & Suen, 1997).

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8 This section describes the situation as it was in 2004.
7.2.1. Collision warning systems for conflicts at intersections

Collision avoidance systems that would be most useful for older drivers will draw the attention of the driver to traffic that approaches the same intersection. Such a collision warning system fits the most important driving difficulty of older drivers: turning left at an intersection. However, intersections also represent the most complex situation to analyse for collision detection, since vehicles can approach from ahead or either side, and can continue straight through the intersection or turn. Consequently, Mitchell and Suen (in 1997) expected equipment to protect against collisions on intersections to take the longest time to develop.

By now, the Japanese Ministry of Land, Infrastructure and Transport has tested a prototype of a system that seems to offer the desired functionalities. The system that was tested is the so-called “Smart Cruise System” (also known as the Advanced Cruise-Assist Highway System AHS), a system that offers seven support services, among which a support system for prevention of crossing collisions and a support system for prevention of right turn collisions (in Japan one drives on the left side of the road). All services were tested separately on a proving ground, amongst others paying attention to safety effects and the convenience for users (Ministry of Land, Infrastructure and Transport, 2002). The effectiveness of the two abovementioned services that would be particularly useful for older drivers was verified by means of a questionnaire. The support for prevention of crossing collisions was found useful by 73% of the users, and the support for prevention of right turn collisions was found useful by 88% of the users (Mizutani, 2001). New tests in 2002, which were aimed at examining the technical feasibility of real-world implementation of the AHS subsystems for support at intersections, showed that problems occurred in the detection of vehicles and in the road-to-vehicle communication. Future research will therefore focus on the reallocation of functions to the infrastructure and the vehicle (Mizutani, 2003).

Another collision warning system that has been tested and that was aimed at the prevention of crashes on intersections, was developed for the DRIVE-II-project EDDIT (Elderly and Disabled Drivers Information Telematics). This system was simulated and tested in a driving simulator. It provided the driver with a colour light indication of whether the next gap in the stream of traffic was long enough to allow a safe turning manoeuvre to be made. If the gap was at or longer than a selected threshold of 6 seconds, a green light
indicated that it was safe to make a turn, otherwise the light changed to red. It remained red until the on-coming vehicle passed the test car, whereupon the device measured the gap to the next vehicle in the on-coming traffic stream. The collision warning system was only active when the test car was stationary and waiting to turn (Oxley & Mitchell, 1995).

The safety effects of the simulated system were inferred from time to collision. The test results showed that time to collision was smaller when subjects were using the system than when they were not. So the system resulted in more near misses. Apparently, the system sometimes advised older drivers to accept a gap that was shorter than the ones they would choose. The time needed to make the turn could play a role here; some drivers made their turning manoeuvre relatively slowly. Based on these results, Oxley (1996) recommends that a collision warning system should have the gap adjustable to match individual driver requirements (e.g., reaction times): uniform settings would be at best unhelpful, at worst dangerous.

All the older participants said that they found the system useful or very useful at night. By day, 63% of the older drivers found it useful or very useful. At the same time, two thirds of the participants considered the information provided by the warning system to be incorrect. Gaps that were safe according to the system were regarded as unsafe and vice versa. Nevertheless, over one third of the participants indicated that the system would make them more confident. Only one participant indicated that he would probably drive more having the system installed. About half of the older drivers would be willing to pay for the system (Oxley & Mitchell, 1995).

Dingus, Jahns, Horowitz and Knipling (1998) argue that crashes at intersections are the result of not noticing crossing vehicles, and not of misjudging the safety of gaps to join or cross. From this point of view, informing the driver about safe gaps to join would not be the most effective way of preventing crashes at intersections. After all, the system that was evaluated in the EDDIT-project was only active when the test car was stationary and waiting to turn, and not when the driver was under the impression that there was no traffic at the intersecting street and kept on driving. Therefore, it is expected that the type of collision warning system that only indicates that traffic is approaching the intersection will have
greater positive road safety effects than a system that indicates that it is safe to cross.

7.2.2. Automated lane changing and merging

Equipment for automated lane changing and merging will assist the driver in selecting a gap and also take care of the actual changing or merging. These systems go further than just informing or warning the driver: they take over vehicle control for a short period of time. Such kind of support is currently not available (Kobayashi, Yuasa, Okamoto, & Horii, 2002). Mitchell and Suen (1997) expected these systems only to be available between 2010 and 2030.

A simplified form of assistance for lane changing and merging is being offered by collision warning systems. Regan, Oxley, Godley, and Tingvall (2001) discuss lane-change collision warning (LCCW) systems and lane-change collision and avoidance (LCCWA) systems. As their names already suggest, the first system only alerts the driver to objects in the vehicle’s blind zones, whereas the second system also automatically steers away from the object. In this respect, the latter comes closer to automated lane changing and merging systems. According to Regan et al., only LCCW systems are currently available on the market.

Evaluation studies of the use of LCCW systems by older adults are not available yet (Regan et al., 2001). In general, LCCW systems have several disadvantages, such as high false alarm rates and the close lateral proximity of vehicles that makes it hard for a driver to safely steer away from an object after being warned by the system (Dingus, Jahns, Horowitz & Knipling, 1998).

7.2.3. Blind spot and obstacle detection

The LCCW systems that were described in the previous section alert the driver for vehicles located in the blind spots of their own vehicle while driving at high speeds. A type of system that provides a similar kind of support, detects objects close to a slow-moving vehicle. These systems can prevent the kind of crashes that can occur while parking. In comparison to the other crash types, this type of crash has less relevance for road safety, both in terms of occurrence and crash severity. However, older adults may be inhibited from driving because of these crashes or from travelling to certain destinations because of the problems they will experience while parking.
In the EDDIT-project that was mentioned earlier, two types of reversing aids were tested. Both reversing aids used sensors that were attached to the rear bumper. These sensors determined the presence of any objects behind the car, and their distance to the rear bumper. This distance was shown to the driver by means of coloured lights (red, amber and green) that were attached either to the dashboard or the shelf (visible in the rear-view mirror). The red light turned on if the object was closer than 0.5 m. One of the systems also had a warning tone that accompanied the light signal if the object was closer than 1 m.

Both reversing aids enabled the older drivers to park much closer to objects and therefore to park more easily in small parking spaces. In terms of safety effects, differences between driving with and without the reversing aids were small. During the first attempts to drive with the reversing aids, the number of collisions was higher than before (i.e., driving without the system installed). However, these collisions could be attributed to getting used to the system.

The older drivers’ responses to both reversing aids were very positive. The majority found them useful and easy to use. The majority of the drivers was also willing to pay for the systems. The price they were willing to pay matched the market price of the systems (Oxley, 1996). Some improvements of the systems that the drivers would like were: detection of objects next to the car (in addition to objects behind the car), and a (louder) warning tone to accompany the light signal (Oxley & Mitchell, 1995).

7.2.4. In-vehicle signing systems

The projection of road signs in the vehicle uses the technology of transmitting the content of a road sign from the roadside to a vehicle and of displaying a replica of the sign, either on a screen in the dashboard or via a head up display. That way, the driver’s attention will be drawn to the (most important) available signs, the signs can be read more easily, and they will be available for a longer period of time. According to Mitchell and Suen (1997), a drawback of these systems is that widespread application will require national or international standards for the transmission of roadside information, and considerable investment in road side transmitters.

Another drawback of in-vehicle sign information system (ISIS), is that they tend to focus the driver’s attention to in-vehicle displays and away from the
roadway (Lee, 1997). According to Lee, the ease of processing ISIS information may compensate for this shift in attention, particularly since ISIS displays will not be subject to environmental factors (rain, snow, and fog) that can obscure roadway signs. However, a greater proportion of the driver’s attention will now be in-vehicle, potentially leaving insufficient attention for environmental scanning. Due to the functional limitations of the older driver, especially their increased difficulty to divide attention between the basic driving task and other activities, ISIS could have more adverse effects on the older adult’s driving behaviour. The location of the in-vehicle display and the way the information is provided are important factors as to whether the safety effects of the in-vehicle signs and warnings will be positive or negative (Luoma & Rämä, 2002; Pauzié, 2002; Perel, 1998; Stamatiadis, 1998).

Luoma and Rämä (2002) have carried out a study in which they tested an information system that presents a selection of the road signs on a display in the vehicle. The signs that were presented to the driver referred to the speed limit, children, and cyclists. Each new sign was preceded by a warning tone. The presented information was offered in four different ways: a) a picture of the sign, b) a picture of the sign combined with an auditory description of the meaning of the sign, c) a picture of the sign combined with auditory feedback based on driver behaviour, or d) a picture of the sign combined with a complete instruction of what the driver is supposed to do (e.g., reduce speed and mind cyclists) for all drivers. The information system was built into an instrumented vehicle. Participants had to cover a route four times with this car. Every time they drove the route they received the information in another way. The order in which the different ways of presentation were offered to the participants was the same for each participant (i.e., no counterbalancing). The route they had to follow was indicated by a navigation system that was part of the same information system. At the end of the experiment, participants were asked to rate the usefulness of the presented information, to rate the effectiveness of the information compared to conventional signing, and to indicate whether they would buy the system if it would present the information in the way they preferred.

As regards the usefulness of the different elements of the information system, participants rated the navigation function, the visual presentation of the signs, and the warning tone very useful. The presentation form that was rated the highest was the sole use of a picture (a), followed by a picture with driver-oriented feedback (c). Participants were in general the least positive
about the picture that was combined with a complete instruction about what to do (d). Older participants (aged 59-86) were, however, more positive about this presentation form than younger participants (aged 18-23).

Eighty-nine percent of the participants were of the opinion that the information system increased the effect of traffic signs and improved traffic safety. On the other hand, many participants reported driving problems while using the system. The most frequently reported problems included unintentional speed reductions and late detection of other road users, vehicles or obstacles on the road. Effects on general driving behaviour were not investigated in this study.

When participants were asked to indicate whether they would be willing to buy a system that presented the information in the way they preferred the most, 75% of the participants indicated that they would. The price they were willing to pay for the system varied from 34 to 504 Euro, with an average of 200 Euro. Older participants were less willing to pay for the system. Whereas all younger participants were willing to pay for the system, only half of the older participants were, and they would also pay less for the system than the younger participants would.

7.2.5. Intelligent cruise control

Systems that offer intelligent cruise control (ICC) (also known as Adaptive Cruise Control (ACC)) not only see to it that the vehicle maintains the same speed, but also incorporate a distance keeping function. Depending on the type of ICC, the system will alert the driver or take over the control of the brakes and the accelerator (see e.g., Hoetink, 2003). Mitchell and Suen (1997) describe a type of ICC that would also reduce speed in response to signals from the road environment. Examples of such signals would be the local speed limit, yield signs, a red traffic light, or a railway crossing. Systems that adapt the speed of the car in response to the local speed limit belong to the category of Intelligent Speed Adaptation (ISA). These systems do not specifically fit the needs of the older driver. However, a system that anticipates the presence of yield signs, stop signs, and/or traffic lights by reducing speed, may contribute to the prevention of an error that is connected with the crash involvement of older drivers: not yielding. The reduced driving speed offers the driver more time to assess the traffic situation and to act accordingly. These systems can be considered as a special type of ICC. Examples of such systems have been developed as part of the
research initiative INVENT and will be tested in the PReVENT Project INTERSAFE.

7.2.6. Driver information systems

Entenmann and Küting (2000) have described a system that gives the driver information about the intersections that he is about to cross. This information system is a navigation system that not only gives route descriptions, but also provides timely information on the crucial elements of the next traffic situation. By giving the driver very early and sequential information, the driver will be able to build up a mental picture of what to expect, at a moment at which his workload is still low. This mental picture will give him the possibility to direct his attention to the most important traffic elements. Given their functional limitations as described in Chapter 2 and 4, a support system that provides this kind of information could be especially useful for older drivers. In fact, the driver information system was actually designed for this group of drivers.

The system proposed by Entenmann and Küting (2000) was only supposed to provide information if the driver arrived at complex intersections. The complexity of intersections was to be derived from the number of traffic lanes, the number of traffic signs and signals, and the yearly number of crashes on the intersection. The information that is provided by the driver information system should be restricted to an indication of the complexity of the intersection, the number of traffic lanes and the traffic objects that deserve attention (e.g., a pedestrian crossing). Since digital maps do not contain this kind of information, Entenmann et al. (2001) carried out a pilot-study to explore the possibilities of adding the abovementioned information to digital maps. This pilot-study was carried out in the framework of the NextMAP project, a partnership of map providers and car manufacturers. It turned out that it was technically feasible to collect and digitise the information that was needed.

As part of the same pilot-study, Entenmann et al. (2001) also carried out a field test to investigate the user acceptance of this kind of driver information system and its effects on driving behaviour. The device that was actually used in this test, supported the driver in adjusting the vehicle speed to the speed limit, in selecting the appropriate lane, and in negotiating intersections. The published test results state that “the information about lanes, speed limits and priority regulations was very beneficial for the driver in demanding urban traffic situations and was very well accepted. The
additional information eases the driving task significantly and increases driving safety compared to a standard navigation system” (Entenmann et al., 2001).

7.3. Preconditions for safe use of ADAS

Knowing which types of ADAS have the most potential to improve the safety of older drivers is not enough to actually improve their safety. The systems will have to be accepted by the user, they will have to be bought, used and trusted, the driver has to be able to understand the information the ADAS is sending to him (via a display or sound), in case more than one ADAS is installed in a car the systems should work together instead of fighting for the attention of the driver and giving him conflicting information, and the support provided by the system(s) should not have any negative safety consequences on other elements of the driving task nor on the behaviour of other drivers. All these preconditions will be dealt with in the next paragraphs.

7.3.1. User acceptance

The results of the EDDIT-study showed that the older drivers that participated in this study were to a large extent willing to consider using and buying the devices that were tested. Moreover, the amount of money they were willing to pay was roughly the same as the market price of the various devices. These findings are consistent with the results of a survey on the purchase behaviour of older adults when buying a car. This survey showed that older adults in general buy smaller cars. However, the cars they buy have more extras than the cars that younger drivers buy. It turns out that older adults are willing to pay for extras such as power steering and electric window control under the condition that these extras meet an existing need (Oxley & Mitchell, 1995).

In a Swedish study (Viborg, 1999), similar results were found. When asked about their attitudes towards 15 in-car information systems, older drivers (65 year olds and older) had a more positive attitude towards the presented ADAS than younger drivers (30-45 year olds). Systems that older adults more often rated as useful as compared to younger drivers, were automatic speed adjustment systems (adjustment to the speed limit or to slippery and foggy conditions), automatic distance adjustment systems, a system that warns the driver by a signal when it is unsafe to cross an intersection, and a
system that warns the driver when it is unsafe to turn left at an intersection. Since the first two systems (partly) take over vehicle control, it seems that older drivers are more willing to accept enforcing systems.

De Waard, Van der Hulst, and Brookhuis (1999) arrived at the same conclusion based on the results of their simulator study on the behavioural effects of an in-car tutoring system. In this study, drivers received auditory and visual clues when they were speeding, not coming to a stop before a stop sign, running a red light, or entering a one-way street on the wrong side. Older (60–75 year olds) as well as younger drivers (30–45 year olds) committed fewer offences when the system gave feedback messages. However, whereas the older participants were pleased with the messages, the younger participants disliked the system.

The abovementioned research results on user acceptance indicate that it is likely that the ADAS that were discussed in the previous sections will be accepted by older drivers as a means to improve their safety. However, whether the introduction of one of these systems will actually result in a reduction of the number of crashes will also be dependent on the design of the particular system.

7.3.2. Design principles for the human machine interface

Older drivers are more susceptible to the consequences of poorly defined ADAS than younger drivers (Stamatiadis 1994; cited in Regan et al., 2001). They generally need more time to carry out secondary tasks while driving (Green, 2001a). Hence it is critically important to bear in mind the possibilities and limitations of older drivers while designing the human machine interface for ADAS (Regan et al., 2001). There are several reports available that describe the current guidelines (see Green (2001b) for an overview). Caird, Chugh, Wilcox, and Dewar (1998) have summarized these guidelines and in addition to that included a section on older driver guidelines. The latter design guidelines are summarized in Table 7.2 along with the functional limitations of older adults they take into account. Note that these functional limitations include those which were mentioned in Table 4.2 of Section 4.6 as being important to take into account while designing human machine interfaces for driver assistance systems (DESIGN).
<table>
<thead>
<tr>
<th><strong>Functional limitations</strong></th>
<th><strong>Relevant design principles</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>General sensory deficits</td>
<td>Use redundant cues, like auditory, visual and tactile feedback</td>
</tr>
<tr>
<td>Visual acuity</td>
<td>Increase character size of textual labels</td>
</tr>
<tr>
<td>Colour vision</td>
<td>Use white colours on a black background</td>
</tr>
<tr>
<td>Night-time visual acuity</td>
<td>Use supplemental illumination for devices used in low-light conditions</td>
</tr>
<tr>
<td>Sensitivity to glare</td>
<td>Use matt finishes for control panels and antiglare coating on displays</td>
</tr>
<tr>
<td>Hearing</td>
<td>Use auditory signals in the range of 1500-2500 Hz range</td>
</tr>
<tr>
<td>Contrast sensitivity and motion perception</td>
<td>Where depth perception is important, provide non-physical cues, such as relative size, interposition, linear position and texture gradient</td>
</tr>
<tr>
<td>Selective attention</td>
<td>Enhance the conspicuousness of critical stimuli through changes of size, contrast, colour or motion</td>
</tr>
<tr>
<td>Perception-reaction time</td>
<td>Give the user sufficient time to respond to a request by the system and provide advanced warnings to provide the driver with enough time to react to the on-coming traffic situation</td>
</tr>
<tr>
<td>Hand dexterity and strength</td>
<td>Use large diameter knobs, textured knob surfaces and controls with low resistance</td>
</tr>
</tbody>
</table>

**Table 7.2.** Functional limitations and relevant design principles (based on Caird et al., 1998 and Gardner-Bonneau & Gosbee, 1997).

Whereas the guidelines in Table 7.2 all have been selected based on the older adult’s functional limitations, it should be kept in mind that designers should also take advantage of the experience that older drivers have. This can be accomplished by using features that are common to them, such as traffic-related icons or features that are common to other products used by older adults (Gardner-Bonneau & Gosbee, 1997).

### 7.3.3. ADAS that work together

So far, various ADAS have been discussed in isolation; while describing the working of the various systems as well as while discussing their effects on driving behaviour. However, the installation of several systems in one car might introduce new problems. It might lead to several displays in the car fighting for the attention of the driver. The driver will have to divide his
attention over the various displays, leading to an observation task that is more complex. Older drivers will suffer the most from that, since age differences become more evident as tasks are becoming more complex. This will result in longer reaction times (see e.g., McDowd & Craik, 1988; Stelmach & Nahom, 1992). Simultaneously sent messages will increase the pressure on the driver even further. In sum, the presence of several, independently functioning systems increases workload, leading to an effect in the opposite direction of what was the objective of the implementation of the ADAS: reducing workload.

Some sort of coordination between the installed ADAS might overcome these difficulties (ETSC, 1999). In addition, it can also prevent systems to send conflicting instructions or, even worse, to carry out conflicting actions. The coordination between systems can be implemented in different ways. Heijer et al. (2001) suggested that ADAS should support the driver in a set of problematic situations instead of separate ADAS that each support the driver in a different situation. Another way of implementing coordination between ADAS uses mediation by a system that decides when which system is allowed to pass what kind of information in what kind of way. Several examples of mediators have been described in the literature (Färber & Färber, 2003; Montanari et al., 2002; Piechulla et al., 2003; Vonk, Van Arem & Hoedemaeker, 2002; Wheatley & Hurwitz, 2001). Most of the mediators use an algorithm to decide whether the workload of the driver is low enough to allow him to receive information from one of the connected systems. Car data (e.g., driving speed, use of steering wheel, use of windscreen wipers, use of headlights) form the input for the algorithm. Dependent on the corresponding level of workload (low, medium or high) and the importance ascribed to the systems that want to inform the driver (e.g., safety system, route information, telephone call), the algorithm does or does not directly pass on the information that has been sent by one of the systems installed. Messages that are not important enough to be passed on directly will be put on hold. Ideally, all messages will be sent to the same display.

7.3.4. Side-effects: human-out-of-the-loop and behavioural adaptation

The ultimate goal of ADAS – in the scope of this thesis – is to improve the safety of the older driver. This not only means that the supported (sub)task should be executed more safely, it also means that the support given should not have any negative safety consequences on the other elements of the driving task. Possible side-effects that are mentioned in the literature are
“human-out-of-the-loop”, disturbances in the construction of situation awareness and behavioural adaptation (see for example Hoc, 2000).

**Human-out-of-the-loop**

The driving task can be seen as a continuous cycle of perception, decision making and action. Each cycle, the driver selects the information that he needs to perform his task, he evaluates the selected information using his knowledge, experience, preferences and emotions, and acts accordingly, thereby changing his environment. Subsequently, these changes can be observed, which closes the loop: there is a dynamic interaction between the driver and his environment (Michon, 1989). If a part of the driving task is taken over by some ADAS (i.e., some part of the task is automated), the driver can be put out of the loop. This can lead to various consequences: loss of skills, reduced alertness and loss of situation awareness, and the transition from a driver who carries out the work himself to a driver who supervises the system. Unfortunately, humans are not as good at supervising as they are at carrying out the actions themselves (Carsten, 2000; Endsley & Kiris, 1995; Wickens & Hollands, 2000).

The negative consequences of automation of the driving task can be prevented by letting the ADAS support the driver instead of replacing him (Heijer et al., 2001). Whereas Endsley and Kiris (1995) have shown that complete automation of a task leads to a loss of situation awareness, Heijer et al. argue that the implementation of supportive ADAS would improve the situation awareness of the driver, especially by improving the perception of the driver. Besides that, the use of supportive systems will preserve the skills of the driver, which is especially important in case of system failure (Heijer et al., 2001; Janssen, 2000; see Shebilske, Goettle & Garland [2000, p. 317] for a theoretical underpinning).

**Behavioural adaptation**

Another factor that may influence the risk reduction that can be expected as a result of the introduction of a support system, is behavioural adaptation. The phenomenon of behavioural adaptation implies that people adapt their behaviour to some of the improvements of a system by taking larger risks (See Dragutinovic, Brookhuis, Hagenzieker, and Marchau (2005) for an overview of the behavioural adaptation effects in response to Advanced Cruise Control). The term behavioural adaptation originates from Evans (1991), but the phenomenon is also known under the terms risk compensation and risk homeostase (Wilde, 1982). According to Howarth (1993), risk reductions are more likely to be achieved if the safety measures
that are implemented are not directly associated with risk reduction and if warning systems give clear and timely warnings about situations and actions that are really risky. The opposite scenario could lead to increased risks: speed limits that are so cautious that they are ignored can result in drivers also ignoring warning signs that actually do indicate a real danger.

Taking larger risks is not the only form of behavioural adaptation that can accompany the introduction of safety measures. Other forms of behavioural adaptation (or modification) that are described in the literature are generalization of behaviour, delegation of responsibility and diffusion of behaviour (Broughton, 1994). Generalization of behaviour means that behaviour that is suitable in certain situations is also displayed in situations in which it is not suitable. For example, infrastructure-based ITS which allow drivers on certain roads to drive at a constant, high speed for a long period of time (in a train of cars), can make normal speeds at regular roads look like a snail’s pace. As a result, speeds at the latter roads will also increase (Broughton, 1994; Janssen, 2000).

Delegation of responsibility means that the driver’s trust in a driver assistance system is so big that he becomes less attentive. In combination with a restricted understanding of what the system does and does not do, this may cause the driver to also rely on the system in situations in which the system does not work (either because the current task does not belong to its functionalities or because the system fails). It is clear what the road safety consequences will be if a traffic situation asks for a reaction, the driver assistance system cannot interfere, and the driver does not realize that he himself has to react or realizes this too late because he is not alert enough. Stanton and Marsden (1997; cited in ETSC, 1999) have demonstrated the reality of this scenario in a simulator study: more than half of the participants were not capable of reacting effectively after a simulated collision warning system failed.

The last form of behavioural adaptation, diffusion of behaviour, refers to the imitation of the behaviour of other drivers. An example of diffusion of behaviour is that the behaviour that is shown by drivers that have a certain system installed in their car (e.g., short gaps, high speeds) is being imitated by drivers that do not have the system at their disposal (ETSC, 1999).

A form of behavioural adaptation that could arise among older adults, is withdrawal of compensation behaviour. This can be illustrated by the
introduction of vision enhancement systems. Older drivers generally compensate for their impaired night-time visual acuity and sensitivity to glare by avoiding to drive at night. As a result, the number of crashes involving older drivers at night is relatively low (Aizenberg & McKenzie, 1997; Hakamies-Blomqvist, 1994b, 1994c; McGwin & Brown, 1999; Zhang et al., 1998). When the large-scale introduction of night vision enhancement systems makes older adults drive again at night, this will increase their mobility and improve their quality of life. However, it has to be seen whether the use of night vision enhancement systems will provide a similar risk compensation for impaired night-time visual acuity as does the older driver’s compensation strategy of not driving at night (Caird et al., 1998; Smiley, 2000).

As adaptive behaviour will not necessarily manifest itself during evaluations in simulators or during field tests, it is difficult for designers to anticipate the influence of behavioural adaptation on the effects of newly designed ADAS. All they can do is use the available knowledge on behavioural adaptation, and design the application in such a way that it can easily be adjusted if driver behaviour gives rise to that (Howarth, 1993).

7.3.5. Interaction between drivers with and without ADAS

Automation of (elements of) the driving task does not only affect the isolated behaviour of the supported driver (i.e., the driver that has the system installed in his car). It can also influence interactions between the supported driver and other road users. Driver support may, for example, lead to cars that – in the eyes of other road users – act like an alien. This "extraterrestrial behaviour" can cause confusion among these other road users, which might result in negative road safety consequences (Heijer et al., 2001). These problems will particularly occur in the period between no and full implementation of the system, a period that can last a couple of decades (ETSC, 1999). In the meantime, systems that automate (parts of) the driving task should be designed in such a way that they imitate the traffic behaviour of real drivers as much as possible.
7.4. Conclusions regarding ADAS that can improve the safety of older drivers

Conclusions cannot be drawn yet about whether certain ADAS can improve the safety of older drivers. Although systems have been developed that appear to fit the needs of the older driver, many are still being developed and not much research has been done on user acceptance and the effects on road user behaviour.

However, some preliminary conclusions can be drawn based on the evaluation of systems in Section 7.2. Collision warning systems for conflicts at intersections, for example, appear to be useful provided that system settings can be adjusted to match the reaction time of the driver. Besides that, there are indications that the safety effects of collision warning systems will be larger for systems that warn the driver for approaching traffic than for systems that just let the driver know when the gap between crossing vehicles is large enough to join or cross the traffic stream. The latter systems usually leave it up to the driver to notice approaching vehicles and to yield to them.

Systems that assist the driver while parking may not be so relevant for reducing the fatality rate of older drivers, but older drivers find them very useful and are also prepared to pay for them. Automated lane changing and merging systems are systems that have not been developed yet.

Examples of systems that assist the driver in paying attention to relevant information, are systems that project roadside traffic signs inside the vehicle. These systems are known as in-vehicle sign information systems. They give the driver a better and longer view of the sign. The drawback is that the driver's attention is temporarily diverted from the road. Caution is therefore required when in-vehicle information systems are introduced. The position of the in-vehicle display (either a display on the dashboard or a projection on the front windscreen) and the manner in which the information is presented will determine whether these systems are good or bad for road safety.

Systems which adjust vehicle speed in the vicinity of traffic lights, yield signs, and/or railway crossings, also draw the driver's attention to relevant information about the traffic situation and give him more time to react. These systems may be seen as special types of intelligent cruise control. Examples of such systems have been developed within the framework of a demonstration project. In a follow-up project, users will test prototypes.
The last system that was evaluated, an information system that assists the
driver in safely passing complex traffic situations, has especially been
developed as assistance to older drivers (Entenmann & Küting, 2000). It is a
promising idea to provide the driver with step by step information in time to
anticipate on coming events. The test results indicate that older drivers
appreciate this system more than an ordinary navigation system, and that the
system also has more positive road safety effects (Entenmann et al., 2001).

In the above discussion of driver assistance systems for older drivers, only
those systems were mentioned whose functionality have the most potential
to improve the safety of this group of road users. As a result of this, three
systems that are frequently mentioned in the literature about older drivers
and ADAS were not dealt with:

1) Night-time vision enhancement systems (UV headlights or infrared
technology);
2) Navigation systems;
3) Mayday systems that automatically send the vehicle location to an
emergency service in the case of a breakdown, crash, or other
emergency.

These systems are helpful for drivers who have difficulties driving in
darkness, those who have difficulties driving in an unfamiliar area, and those
who have feelings of insecurity respectively. Therefore, these systems are
especially suitable for improving the mobility of older drivers. Mayday
systems can also shorten the time before receiving medical treatment,
thereby reducing injury severity (Caird, 2004a). The other two systems may
reduce crash rate by compensating for impaired night-time acuity or by
preventing searching. However, whether or not these systems will lead to a
reduction in the number of injuries among older drivers depends on the size
of the crash rate reduction, which should be larger than the increase in
exposure as a result of system usage.

Returning to the ADAS that are aimed at an improvement of the safety of the
older driver, much research remains to be done. First of all, initiatives like
those of Entenmann and Küting (2000) and the EDDIT-project (Oxley &
Mitchell, 1995) will have to be followed to arrive at a situation in which more
ADAS are being developed that are aimed at the special safety needs of older
drivers. Besides that, existing ADAS should more often be evaluated using
both younger and older drivers. Only then it will be possible to draw
conclusions on whether the systems that seem to have the best potential to
improve the safety of older drivers, actually do improve the older driver’s safety. As Green (2001a) states, older drivers experience considerably more difficulty in completing telematics tasks, and therefore it is essential that safety and usability evaluations focus on them. If the older drivers are able to complete a task safely and easily, then other drivers will be able to as well.

In the next chapter, a simulator study is described in which some of the ADAS that are considered to be the most promising for improving the safety of older drivers were examined on their effects on driving behaviour and workload of, and acceptance by younger and older drivers.