

OLDER DRIVERS AND ADAS – Which Systems Improve Road Safety? –

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In the coming decades, the number of older drivers that experiences difficulties in traffic as a result of functional limitations will strongly increase. Advanced Driver Assistance Systems (ADAS) could resolve some of these difficulties, by providing personal assistance in a road environment that does not always allow for the possibilities and limitations of the older road user. As a result, ADAS would extend the older adult's safe mobility as a driver.

The aim of this paper is to identify the driver tasks for which assistance is most desirable from a road safety perspective. It is assumed that the most promising ADAS in this respect are those that support the relative weaknesses of the older driver. ADAS should not take over the tasks the older driver is actually quite good at. To identify the strengths and weaknesses of the older driver, a literature review is conducted. Various theoretical perspectives are examined, among which the human factors approach, cognitive psychology, and game theory. This results in a list of the relative weaknesses of the older driver. To further specify the kinds of support most needed, we look at the relation between the weaknesses identified, the problems that older drivers encounter in traffic as a result of these weaknesses, and the resulting number of crashes. This amounts to a shortlist of desired types of support.

Next, based on the available literature, relevant ADAS are discussed in terms of their availability, their effects on safety and the willingness of older drivers to use and buy them. One of the conclusions is that only very few of the types of support that are thought to be most beneficial to the safety of older drivers are provided by the ADAS that are currently available.

Key Words: Older drivers, ADAS, Road safety, Models of driver behaviour, Driver needs

1. INTRODUCTION

In many countries all over the world, the number of older people has increased during the last decades and will continue to do so. In the Netherlands, for example, the share of people of the age of 65 and older has gradually increased from 11.5 % in 1980 up till 13.8 % in 2004. According to a prognosis of Statistics Netherlands (CBS), the share of the 65 year olds and older will increase more rapidly after 2010 and reach 23.6% in 2040¹. In absolute numbers this will amount to more than 4 million people of the age of 65 and above. A substantial part will be much older than 65. At this moment in time there are approximately 1 million people older than 75. CBS expects that this number will have grown to 1.3 million in 2020, and in 2050 will have reached its maximum of 2.1 million. The percentage of people having difficulties in traffic due to functional limitations is clearly larger among the old-old than among the young-old road users. This not only applies to older pedestrians and cyclists, but also to older drivers. Because the group of older persons is getting increasingly larger, it is important for road safety policy makers to pay more attention to the possibilities and limitations of this group of road users².

The road safety of older road users is to a large extent determined by two factors: functional limitations and physical vulnerability. Both factors contribute to the relatively high death rate among older road users as a result of crashes. Taking the distances travelled into account, this rate is about six times higher for the 75 year olds and older than for the average for all ages. That of the 65-74 year olds is much lower than that of the 75 year olds and older³. According to some researchers, there is a third reason for a high death rate: a low annual mileage. These researchers argue that if risk groups were not only determined based on age but also on annual mileage, the crash rate of older drivers would not be higher than that of younger drivers⁴.

The most important cause of the high death rate among the 75 year olds and older is their greater physical vulnerability. If they are involved in a crash, their chance of dying as a result of that crash is higher than it is for younger drivers. In addition, functional limitations can lead to the older adults being involved in certain types of crashes more often. The crash type that is characteristic for older adults occurs while turning left at an intersection⁵⁻¹⁰.

Taking into account the abovementioned causes of

the high death rate among older drivers, a set of measures that is aimed at reducing the death rate of older adults should at least include measures that are aimed at reducing injury severity. But measures that can reduce the crash involvement of older adults also contribute to a reduction of their death rate. Examples of such measures are: providing education and information for older adults as well as for younger road users, infrastructural adaptations, and driver assistance systems^{11,12}.

This paper will focus on the latter type of measures. Its aim is to identify those ADAS that have the most potential to reduce the crash involvement of older drivers and as a result of that could improve their road safety (see for example Wegman & Aarts¹³). The question of which ADAS are able to improve road safety is usually answered by looking at the available ADAS and their effects on driver behaviour. In this paper the question will be answered by looking at the needs of the driver, more specifically the needs of the older driver. It is assumed that ADAS will be most capable of reducing the crash involvement of older drivers if they support the relative weaknesses of the driver. Therefore, this paper starts with a study of the strengths and weaknesses of older drivers. These strengths and weaknesses will be deduced from the literature that originates from several theoretical perspectives on human functioning: Fuller’s task-capability interface model, the human factors approach, cognitive psychology, and game theory. The result is a list of the relative weaknesses of the older driver and the difficulties that older drivers encounter in traffic as a result of these weaknesses.

To be able to rate the relevance of the weaknesses to road safety, the weaknesses are then compared with crash data. Those weaknesses that have a substantial influence on road safety, as indicated by the percentage of crashes that could have been avoided if the weakness would not have existed (or would have been compensated for by, for example, ADAS), are considered to indicate a need for support. The result is a shortlist of desired types of support.

On the basis of this list, we then select ADAS that seem to provide one or more of these kinds of support. These ADAS are described based on the available literature and – as far as possible – judged on their pros and cons. Finally, regardless of the type of ADAS, we discuss the preconditions ADAS should fulfil to actually be used by older drivers, to actually have positive effects on road safety, and to prevent them from having negative effects on road safety.

2. THEORETICAL FRAMEWORK

The theoretical framework that is used in this paper to identify the relative weaknesses of the older driver, includes the human factors approach, cognitive psychological models, game theory and Fuller’s task-capability interface model¹⁴⁻¹⁶. In the next sections, the main emphasis of each of these theories will be described, together with their “opinions” about the strengths and weaknesses of the older driver. While reading these sections, it should be kept in mind that these models are used as a source of information as to what humans are relatively good and bad at (relatively bad can be interpreted as “worse than average”, or “a higher chance of being one of the causes of crash occurrence”). These models will not be used to test a hypothesis about some relationship. The reason for choosing these models and not other ones, or not just one theory, is that these theories and models are considered to be relevant for describing traffic behaviour and, more importantly, because they are complementary. The latter will be shown in the next section, while describing Fuller’s model.

2.1 Fuller’s task-capability interface model

The task-capability interface model of Fuller is a model that brings together the capabilities of the road user and the demands of the road environment¹⁴⁻¹⁶. The factors that determine the capabilities of the road user are depicted at the upper left of Figure 1, whereas the factors that determine the task demands of the road environment are depicted on the bottom right.

One of the interesting aspects of Fuller’s model is the concept of task difficulty. This concept is the result of a comparison of capabilities and task demands. If the ca-

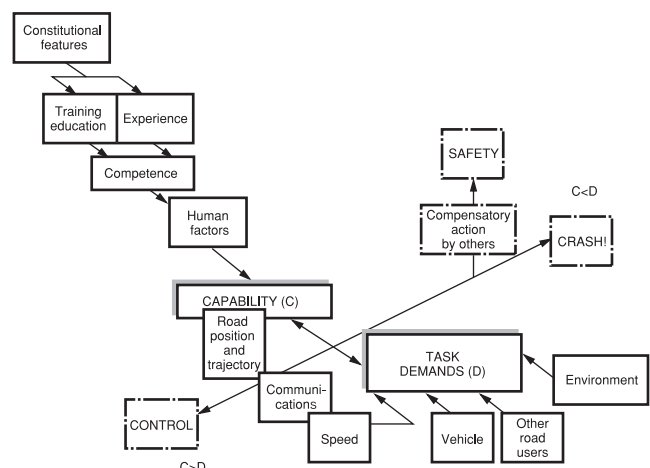


Fig. 1 Fuller’s task-capability interface model¹⁵

pabilities of the road user are higher than the task demands, the task will be easy and the driver will be in command of the situation. However, if the task demands are higher than the capabilities, the task will be difficult and the situation might end in a crash. Fortunately, the driver has several opportunities to intervene. By lowering his driving speed, changing his road position or trajectory, or by communicating with other drivers. Thus crashes are not inevitable. Especially since the other road users can also take compensatory actions. Finally, the chance that crashes will occur can also be reduced by lowering the task demand through infrastructural adjustments and/or vehicle adjustments. An example of the latter is the use of ADAS that support the driver.

According to Fuller's task-capability interface model, the strength of humans is implied in their competences and momentary capabilities, and in the way they cope with discrepancies between their momentary capabilities and task demands. The better a driver copes with the latter discrepancies (by communicating with other road users, adjusting his position on the road and/or his speed), the more he is in control of his weaknesses. These weaknesses are the result of his mental and physical condition, and of variable human factors such as fatigue, emotions, alcohol and other drugs, stress, distraction and motivation.

When people age, their mental and physical condition generally declines. This can be regarded as an extra weakness of the older adult. On the other hand, older drivers usually have a great deal of driving experience. This experience enables them to anticipate the situations they will encounter. Knowing beforehand what will happen will give them extra time to think and act, thereby (partly) compensating for possible mental and/or physical degeneration. It should be mentioned, however, that driving experience might get outdated. If so, it will not give accurate information on how to act in a certain situation anymore.

Another difference between the older adult and the average, somewhat younger driver, is that the older driver is better able to arm himself against the human factors that might influence his momentary capabilities. A first argument in favour of this is that older adults usually have a lower need for sensation seeking¹⁷. As a result, they will be less prone to manoeuvre themselves into risky (traffic) situations. Several studies have shown that older drivers indeed drive less often under the influence of alcohol than younger drivers do and that older drivers more often comply with traffic rules^{10,18}. Furthermore, older adults might profit from the fact that they have more

difficulties sharing their attention between various tasks. Having more difficulties sharing attention, they will be less inclined to combine driving with other not driving related activities such as worrying about problems at work, listening to or operating a radio or CD player and having a (telephone) conversation^{2,19}.

One can conclude from Fuller's task-capability interface model that ADAS should lower the task demands of driving to compensate for the reduced momentary capabilities of the ageing driver. This reduction of the momentary capabilities of the older driver is primarily the result of his mental and physical condition.

The other theoretical perspectives that are included in our theoretical framework, each focus on a different part of Figure 1. The human factors approach shows what the boundaries of human performance (i.e. their capabilities) are, and how designers (of infrastructure, vehicles, and ADAS) should take these boundaries into account. Cognitive psychology focuses on how people deal with differences between capabilities and task demands: "how can we make life easier?". Game theory, as our fourth theoretical perspective, focuses on how we anticipate the actions of others (communication).

2.2 Human factors approach

The human factors approach looks at the boundaries of human information acquisition and processing. Some of the aspects of information processing that decline as people age are vision and perception, hearing, selective and divided attention, speed of information processing, muscle strength, and manual dexterity.

Visual functions that decrease as people age are visual acuity, peripheral vision, visual acuity in poor light and darkness adaptation, contrast sensitivity, detection of movement, and colour vision²⁰⁻²³. It is evident that good vision is very important for safe driving. Motion perception, for example, is important for being able to detect vehicles driving on a crossing road and to estimate their speed, but it is also needed for being able to detect changes in the speed of vehicles straight ahead, i.e. stopping, slowing down, speeding up, and reversing^{20,23}. For car drivers, hearing is perhaps not as critical a sense as vision, but it is potentially an important component of safe driving. As drivers age, they become less able to hear the higher frequencies which provide directional cues, and spatial sensitivity to sound is impaired as a result^{11,24}. At the same time, it becomes more difficult for the older driver to filter out unwanted noises¹¹.

The above-mentioned age-related declines in sensory abilities have an impact on the input the driver re-

ceives from other road users and the infrastructure, but also from ADAS. Perceptual and cognitive processes are needed to select the appropriate information, interpret it, and make decisions which must then be translated into an appropriate driving action. Some of these processes decline as people grow older, including the ability to maintain vigilance, selective and divided attention, short-term memory, and information-processing speed^{11,25-27}.

Physical abilities that decline as people get older are reduced joint flexibility, reduced muscular strength, and reduced manual dexterity. These age-related changes can influence the ability to get in and out of a car, operate the vehicle, and can influence injury and recovery²². A reduction in manual dexterity can also interfere with programming ADAS that require coordinated finger movements²⁸.

It should be kept in mind, however, that the age at which the above-mentioned declines start as well as the rate at which these declines continue differ from person to person. Besides that, it is good to remember that compensation is often possible (for example by not driving at night). Nevertheless, the human factors approach tells us that ADAS could meet a need if it helps the older driver to observe his environment, of course under the precondition that the ADAS itself (or its human machine interface) takes the older driver's declined sensory abilities into account.

2.3 Cognitive psychological models

Cognitive psychology offers us several clues as to how the boundaries of human information processing can be compensated for. Not only by the driver himself, but also by road authorities.

Examples of compensatory action that the driver can take, are travelling at particular times, following a particular route, and/or driving at a lower speed. These examples all originate from the hierarchical structure of the driving task. Michon²⁹ distinguished three task levels: the strategic level, the tactical (or manoeuvring) level and the operational (or control) level. Time pressure is the highest on the operational level (e.g. steering, braking). By making certain choices on the other, higher levels, the driver can lower time pressure. Strategic choices such as a particular route or time (e.g. not driving during peak hours), or tactical choices such as driving at a particular speed or maintaining a particular headway, give the driver more time to act on the operational level.

Another thing that cognitive psychology tells us is that driving experience (and other kinds of experiences) results in mental models that help the driver in choosing

the action that is appropriate for the situation he is in. Elements of the traffic situation trigger the appropriate action without the driver having to take into consideration every possible action (see for example Wickens & Hollands³⁰). Designers should be aware of these mental models and the way they are triggered. If a (new) situation looks similar to a well-known situation but in fact is completely different and also requires different actions, mental models will work counterproductive. Especially for older drivers, since they need more time to recall planned actions³¹. To give a simple example, if the colour red always means that something is forbidden, don't use red arrows to indicate the right direction to leave the car park. These mental models should also be taken into account by designers of ADAS and their human machine interface.

2.4 Game theory

Game theory is about decision making and anticipating the likely reaction of the other ones involved³². A famous example that originates from this theory is the so-called prisoner's dilemma in which suspects of a crime have to decide whether they should talk or remain silent about the other's contribution to the crime committed.

A traffic-related application of game theory concerns giving right-of-way (yielding) and the expectations that one has of what the other road user will do. When approaching a major road, one will look around to see which other road users will arrive at the intersection at the same time, how they behave, in what way they pose a threat (mass and speed of their vehicle), and who has priority. Based on this information the driver will work out who will be the first one to cross the intersection, who will be next, and when it will be his turn. For a safe transaction it is important that every road user can see all the other road users and that everyone knows what is expected of him. These preconditions will not always be satisfied. Especially not if the visual functions of the driver decline. Besides that, people will not always be able to objectively decide on the right (and safe) order in which road users may pass the intersection. Their decision may be influenced by the hurry they are in, or by their state of mind at the time they arrive at the intersection. So from a game theoretical perspective one could say that people are relatively bad at perceiving all the relevant information that is needed to make the right decision, and relatively bad at taking decisions objectively.

ADAS could provide support by giving timely information on who is arriving at the intersection and what is about to happen (including the priority regulation). It

can also help in making the right decision based on the available information. But we should be reluctant to let ADAS take over control. One important precondition for safe interventions by ADAS from a game theoretical perspective, is that cars with ADAS will have to behave the same way as they would have done if they were operated by humans. This means that they should not only take into account what their own “boss” does, but also anticipate actions of others. Otherwise, their behaviour might come across as behaviour of an alien or at least as antisocial behaviour to drivers not having the ADAS, with all its consequences such as crashes and frustrated road users that take their frustration out on others.

3. DRIVER NEEDS

The theoretical framework provided us with information about the relative weaknesses of the older adult. Note that not every weakness of the driver has negative road safety consequences. After all, many weaknesses can be compensated for. Take for example restricted peripheral vision; that can be compensated for by increased movements of head and neck. Only when a combination of several weaknesses makes it impossible to take compensatory action or to act in the available time period, driving problems will arise. Depending on the circumstances (remember the compensatory action that fellow road users can take) these problems might in the end result in a crash.

We could state that the relative weaknesses of the older driver create an objective need for the development of ADAS that offer driver support on these specific areas. This objective need for support can be formulated more precisely by indicating the driving-related difficulties that arise as a result of these weaknesses. By quantifying these difficulties based on how often these problems result in crashes, we also have a standard that can be used to rank the need for different kinds of support.

Table 1 shows the results of such an exercise. In horizontal direction, the table successively shows the weaknesses of the older adult, the difficulties he is faced with as a result of these weaknesses (accompanied by the extent to which these problems contribute to the total number of crashes), and the type of support that could prevent such driving-related difficulties. Knowledge of the weaknesses of the older driver is not only of use for the identification of their need for support, but also for the design of supportive systems: how to provide support. The weaknesses that should be taken into account when

designing the human machine interface for ADAS are indicated by “(HMI)” in the right-hand column. In vertical direction, the table reflects the stages of information processing.

The relevance of the driving-related difficulties (middle column) to road safety is derived from Malaterre and Fontaine³³. They have investigated the relation between crash types and the need for information and assistance using in-depth crash data. The percentage of crashes that could be avoided by providing the driver with information that is relevant to a certain driving problem was used as an indicator of the relevance of that driving problem to road safety. In Table 1 this relevance is expressed in terms of plus signs; the more plus signs, the more relevant it is to road safety (see the Appendix for the data of Malaterre & Fontaine³³).

Using the percentages of Malaterre and Fontaine³³ has the disadvantage of them being based on the total number of crashes and therefore on the “average” road user. Several studies have indicated that older adults are more often involved in crashes while turning left and while merging⁵⁻¹⁰. In this respect, the percentages of Malaterre and Fontaine³³ underestimate the relevance to road safety of some of the driving-related difficulties of older adults. In Table 1 this is corrected for by giving the relevant difficulties an extra plus sign (and the code OD).

Based on Table 1, we can conclude that the most important need for support, from a road safety perspective, stems from the following driving-related difficulties (printed in bold in Table 1) and weaknesses that cause them (relevant to 5% or more of the total number of crashes of older drivers):

- a) difficulty judging whether fellow road users are moving and at what speed they approach the intersection (motion perception);
- b) overlooking other road users while merging and changing lanes (peripheral vision and flexibility of head and neck);
- c) overlooking traffic signs and signals (selective attention);
- d) reaction time increases as the complexity of the traffic situation increases (speed of processing information and decision making, performance under pressure of time).

The right-hand column of Table 1 describes the kind of assistance that is needed. These descriptions are simply derived from the driving-related difficulties. Only the type of assistance is mentioned, not the way in which the assistance could be provided or which existing devices already provide for it. Based on the above-men-

Table 1 Weaknesses of older adults, driving-related difficulties and assistance needed, prioritized by their relevance to road safety

WEAKNESSES	DRIVING RELATED DIFFICULTIES AND THEIR RELEVANCE TO ROAD SAFETY	ASSISTANCE NEEDED
<i>Vision and hearing</i>		
Peripheral vision	Overlooking other road users while merging or changing lanes (7: ++ OD)¹	Signalling objects that are located in the driver's blind spot
Nighttime visual acuity	Difficulty seeing pedestrians and other objects at night and reading signs (x)	Artificially lighting objects (other road users and road design elements)
Sensitivity to glare	Temporary loss of visual information (x)	Prevent glare (HMI)
Contrast sensitivity	Difficulty reading signs and in-car displays and difficulty with depth perception and estimating the speed of other road users (11: + OD)	(HMI) Draw attention to approaching traffic
Colour vision	Difficulty discriminating between similar colours; relevant to reading signs and in-vehicle displays (x)	(HMI)
Motion perception	Difficulty judging the movement of fellow road users and their approach speed (6: +++)	Draw attention to approaching traffic
Hearing	Difficulty locating the direction of sounds and ignoring noise (x)	(HMI)
<i>Cognitive processing and decision making</i>		
Divided attention	Driving task performance gets worse when other tasks have to be performed simultaneously; see also 'speed of information processing and decision making' (x)	(HMI)
Selective attention	Overlooking traffic signs and signals (3: ++)	Assist the driver in directing his attention to relevant information
Speed of processing information and making decisions	Reaction time increases as the complexity of the traffic situation increases (3: ++)	Provide prior knowledge on the next traffic situation
Performing tasks consciously	Difficulty driving in an unfamiliar environment (x)	Provide prior knowledge on the next traffic situation
<i>Physical changes</i>		
Flexibility of head and neck	Overlooking fellow road users when merging or changing lanes (7: ++ OD)	Signalling objects that are located in the driver's blind spot
Manual dexterity and strength	Difficulty programming on instrument panels (x)	(HMI)
<i>Interaction with other road users</i>		
Performance under pressure of time	Suboptimal decisions (3: ++)	Provide prior knowledge on the next traffic situation
Insight in the behaviour of other road users	Difficulty predicting the intentions of other road users (14: +)	Draw attention to approaching traffic and its behaviour

¹ The text between the brackets refers to the data in the Appendix. The numbers correspond to the numbers preceding the needs for information and/or assistance in the Appendix (first column). The plus signs, "0" and "x" refer to the percentage of the total number of crashes that could be avoided if the need would be met: >10%=+++; 5-10%=++; 2,5-5%=+; < 2,5% = 0; x=no data available (second column of the Appendix). 'OD' (Older Driver) means that one plus sign is added to account for the underestimation of the number of crashes involving older drivers (third column of the Appendix). The most important needs for support are printed in bold. See text for further explanation.

tioned driving-related difficulties, the assistive devices most needed will:

- 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.

In the next section, systems are described that already seem to provide these kinds of support, or will do so in the near future.

4. SUPPORT SYSTEMS THAT HAVE THE POTENTIAL TO IMPROVE ROAD SAFETY FOR OLDER DRIVERS

Several studies have mentioned ADAS that might be able to provide tailored assistance for older drivers³⁴⁻³⁶. ADAS that according to Mitchell and Suen³⁴ might be able to provide assistance for the difficulties resulting from limitations in motion perception, peripheral vision, selective attention and decreased speed of processing information and decision making are summarized in Table 2. In the next paragraphs, each of these systems will be described based on what they do, what their pros and

Table 2 Desired functionalities and ADAS that seem to offer them (adapted from Mitchell and Suen³⁴)

Functionality	ADAS
Draw attention to approaching traffic	- collision warning systems aimed at intersections - automated lane changing and merging systems
Signal road users located in the driver's blind spot	- automated lane changing and merging systems - blind spot and obstacle detection systems
Assist the driver in directing his attention to relevant information	- in-vehicle signing systems - special intelligent cruise control
Provide prior knowledge on the next traffic situation	- systems that give information on the characteristics of complex intersections the driver is about to cross

cons are, whether they are already on the market, and whether they have been tested by older drivers and if so what the results of these tests were.

4.1 Collision warning systems

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 on 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 turn³⁴. Consequently, Mitchell and Suen³⁴ 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 they drive 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 users³⁷. The effectiveness of the two above-mentioned 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 users³⁸. New tests in 2002, that were aimed at examining the technical feasibility of real-world implementation of the AHS subsys-

tems 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 vehicle³⁹.

Another collision warning system that is 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 turn⁴⁰.

The safety effects of the simulated system were deduced from the time to collision. The test results showed that the 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 is shorter than they would choose. The time needed to make the turn could play a part here; some drivers made their turning manoeuvre relatively slowly. Based on these results, Oxley⁴¹ 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 adult subjects said that the system was useful or very useful at night. By day, 63% of the older drivers found it useful or very useful. About half of the older drivers would be willing to pay for the system⁴⁰.

4.2 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. Mitchell and Suen³⁴ expect 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 Tingvall⁴² 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.⁴², only LCCW systems are currently available on the market.

Evaluation studies of the use of LCCW systems by older adults are not available yet. 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 system⁴³.

4.3 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 some destinations because of the problems they experience while parking. In the EDDIT-project that was mentioned earlier, two types of reversing aids were tested. Both reversing aids enabled the drivers to park much closer to objects and therefore to park more easily in small parking spaces. 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. 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 sound that accompanies the light signal^{40,41}.

4.4 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 Suen³⁴, 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. In addition, Lee⁴⁴ points at the tendency of In-vehicle Signing Information Systems (ISIS) to focus the driver's attention to in-vehicle displays and away from the roadway. 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 scanning⁴⁴. 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 negative⁴⁵⁻⁴⁷.

4.5 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 accelerator⁴⁸. Mitchell and Suen³⁴ 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. But a system that anticipates the presence of yield signs, stop signs, or traffic lights by reducing speed could contribute to the prevention of a frequently made error at crashes with 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.

4.6 Driver information systems

Entenmann and Küting⁴⁹ have described a system that gives the driver information on the characteristics of complex intersections that he is about to cross. This driver information system is a navigation system not only giving route descriptions, but also providing 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 task load 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 the section on the human factors approach, 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 Küting⁴⁹ was only supposed to provide information when the driver arrives at more complex intersections. The complexity of the intersection should be derived from the number of traffic lanes, the number of traffic signs and signals and the yearly number of crashes on that 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 currently do not contain this kind of information, Entenmann, Hummelsheim, Sabel, Bendaifi, Williams, Loewenau, Marquet, and Lilli⁴⁸ carried out a pilot-study to explore the possibilities of adding the above-mentioned information to digital maps. This pilot-study was carried out in the framework of the Next-MAP 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.⁴⁸ 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”⁷⁴⁸.

5. PRECONDITIONS FOR SAFE USE

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.

5.1 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. The 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 need⁴⁰.

In a more recent Swedish study⁵¹, 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 Brookhuis⁵² 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 adults (60–75 year olds) as well as the younger drivers (30–45 year olds) committed fewer offences when the system gave feedback messages. But whereas the older adults were pleased with the messages, the younger drivers disliked the system.

The above-mentioned 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. But whether the introduction of one of those systems will actually result in a reduction of the number of crashes will also be dependent on the design of that particular system.

5.2 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. 42). They generally need more time to carry out secondary tasks while driving⁵³. Hence it is critically important to bear in mind the possibilities and limitations of older drivers while designing the human machine interface for ADAS⁴¹. There are several reports available that describe the current guidelines (see Green⁵⁴ for an overview). Caird, Chugh, Wilcox, and Dewar⁵⁵ have summarized these guidelines and in addition to that included a section on older driver guidelines. The latter design guidelines are summarized in Table 3 along with the functional limitations of older adults they take into account. The functional limitations correspond to the limitations mentioned in Table 1 (HMI). Some of the descriptions have been taken from Gardner-Bonneau and Gosbee⁵⁶.

Whereas the guidelines in Table 3 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 familiar features that are common to them, such as traffic-related icons or features that are common to other products used by older adults⁵⁶.

5.3 ADAS that work together

So far, ADAS have been discussed in isolation; while describing the working of the various systems as well as while discussing their effects on driving behaviour. But 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. 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 for example McDowd and Craik⁵⁷). Simultaneously sent messages will increase the pressure on the driver even further. In sum, the presence of several, independently functioning systems increases the task load, leading to an effect in the opposite direction of what was the objective of the implementation of the ADAS: lowering the task load.

Some sort of coordination between the installed ADAS might overcome these difficulties⁵⁸. And 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.⁵⁹ suggested that ADAS should be able to 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

Table 3 Functional limitations and relevant design principles based on Caird et al.⁵⁵ and Gardner-Bonneau and Gosbee⁵⁶)

Functional limitations	Relevant design principles
General sensory deficits	Use redundant cues, like auditory, visual and tactile feedback
Visual acuity	Increase character size of textual labels
Colour vision	Use white colours on a black background
Diminished low-light vision	Use supplemental illumination for devices used in low-light conditions
Sensitivity to glare	Use matt finishes for control panels and antiglare coating on displays
Hearing	Use auditory signals in the range of 1500-2500 Hz range
Depth perception	Where depth perception is important, provide non-physical cues, such as relative size, interposition, linear position and texture gradient
Selective attention	Enhance the conspicuity of critical stimuli through changes of size, contrast, colour or motion
Perception-reaction time	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
Hand dexterity and strength	Use large diameter knobs, textured knob surfaces and controls with low resistance

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 literature⁶⁰⁻⁶³.

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

The ultimate goal of ADAS – in the scope of this paper – is to improve the safety of the 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 Hoc⁶⁴).

5.4.1 Human-out-of-the-loop

The driving task can be seen as a continuous cycle of observation, 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 man and his environment⁶⁵. If a part of the driving task is taken over by some ADAS (i.e. automated), man 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^{30,66,67}.

The negative consequences of automation of the driving task can be prevented by letting the ADAS support the driver instead of replacing him⁵⁹. Whereas Endsley and Kiris⁶⁷ have shown that complete automation of a task leads to a loss of situation awareness, Heijer et al.⁵⁹ believe 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^{59,68,69}.

5.4.2 Behavioural adaptation

A second factor that might have a negative effect on 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 bigger chances (see Dragutinic, Brookhuis, Hagenzieker, and Marchau⁷⁰ for an overview of the behavioural adaptation effects in response to Advanced Cruise Control). The term behavioural adaptation originates from Evans⁷¹ but the phenomenon is also known under the terms risk compensation and risk homeostase⁷².

A form of behavioural adaptation that could arise among older adults, is the 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 low⁶⁻⁹. 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^{55,73}.

5.5 Interaction between drivers with and without ADAS

Effects of the automation of (elements of) the driving task are not limited to the behaviour of the supported driver (the driver that has the system installed in his car). It is possible that, in the eyes of the other road users, the support given by an ADAS makes the car act “like an alien”. This “extraterrestrial behaviour” can cause confusion among the other road users which might result in negative road safety consequences⁵⁹. These problems will particularly occur in the period between no and full implementation of the system, a period that can last a couple of decades⁵⁸. 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 the driver as much as possible.

6. CONCLUSIONS AND RECOMMENDATIONS

Based on a literature review, this paper identified those ADAS that have the most potential to reduce the crash involvement of older drivers. Most studies that have

the aim to identify ADAS that can improve road safety start looking at the available ADAS and their effects on driver behaviour. This study, however, looked at the needs of the driver, more specifically the needs of the older driver. It was assumed that ADAS will be most capable of reducing the crash involvement of older drivers if they support the relative weaknesses of the driver. These weaknesses were identified by studying various theories on human functioning. Based on the identified weaknesses and their relevance to road safety, it was concluded that to have the biggest potential to improve the road safety of older drivers, 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 seem 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. However, it turns out that many of these systems are still being developed and not much research has been done on user acceptance and the effects on road user behaviour. As a result, little can be said on whether these systems - when available - will actually be used by older drivers and will actually improve their safety.

Thus, with respect to 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 Küting⁴⁹ and the EDDIT-project⁴⁰ 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 we will be able 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.

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APPENDIX

Needs regarding information and assistance and the percentage of crashes that could be avoided if the need would be met (adapted from Malaterre and Fontaine³³)

Needs regarding information and/or assistance	Percentage of the total number of crashes that could have been avoided if the need had been satisfied	Is this percentage higher for crashes older drivers are involved in? ¹
<i>Monitoring driver and vehicle condition</i>		
1. Driver status (fatigue, driving under the influence of alcohol or drugs)	8.4 %	
2. Vehicle status (mechanical defects)	1.1 %	
<i>Timely detection</i>		
3. Timely detection of a road-related difficulty	5.0 %	
4. Obstacle detection	4.4 %	
5. Timely detection of oncoming road users that are not visible due to trees, building, etcetera	7.1 %	
6. Timely detection of road users that are on an intersecting lane at an intersection	19.1 %	OD
7. Detection of road users that are hidden in vehicle blind spots	4.0 %	OD
8. Detection of pedestrians	5.8 %	OD
<i>Estimating time and speed</i>		
9. Correctly assessing speeds in relation to road conditions	3.7 %	
10. Timely assessment of speed differences between the vehicles in front and ones own vehicle	3.9 %	
11. Estimating the collision course with cross traffic	0.9 %	OD
12. Assessing gaps when overtaking or changing lane	0.6 %	OD
13. Assessing gaps when joining or cutting across a traffic flow	0.6 %	OD
<i>Predicting the behaviour of other road users</i>		
14. Predicting the behaviour of other road users regarding yielding and stopping	4.7 %	
15. Predicting the manoeuvres of other road users	7.3 %	
16. Predicting the behaviour of pedestrians	1.9 %	
<i>Being able to control one's vehicle</i>		
17. Vehicle control	1.8 %	

¹ OD (Older Driver) in the right column means that the percentage mentioned in the middle column is an underestimation of the percentage that could be avoided of the total number of crashes older drivers are involved in.