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Older Drivers

Please refer to this document as: DaCoTA (2012) Older Drivers, Deliverable 4.8k of the EC FP7 project DaCoTA

Project co-financed by the European Commission Directorate General for Mobility & Transport

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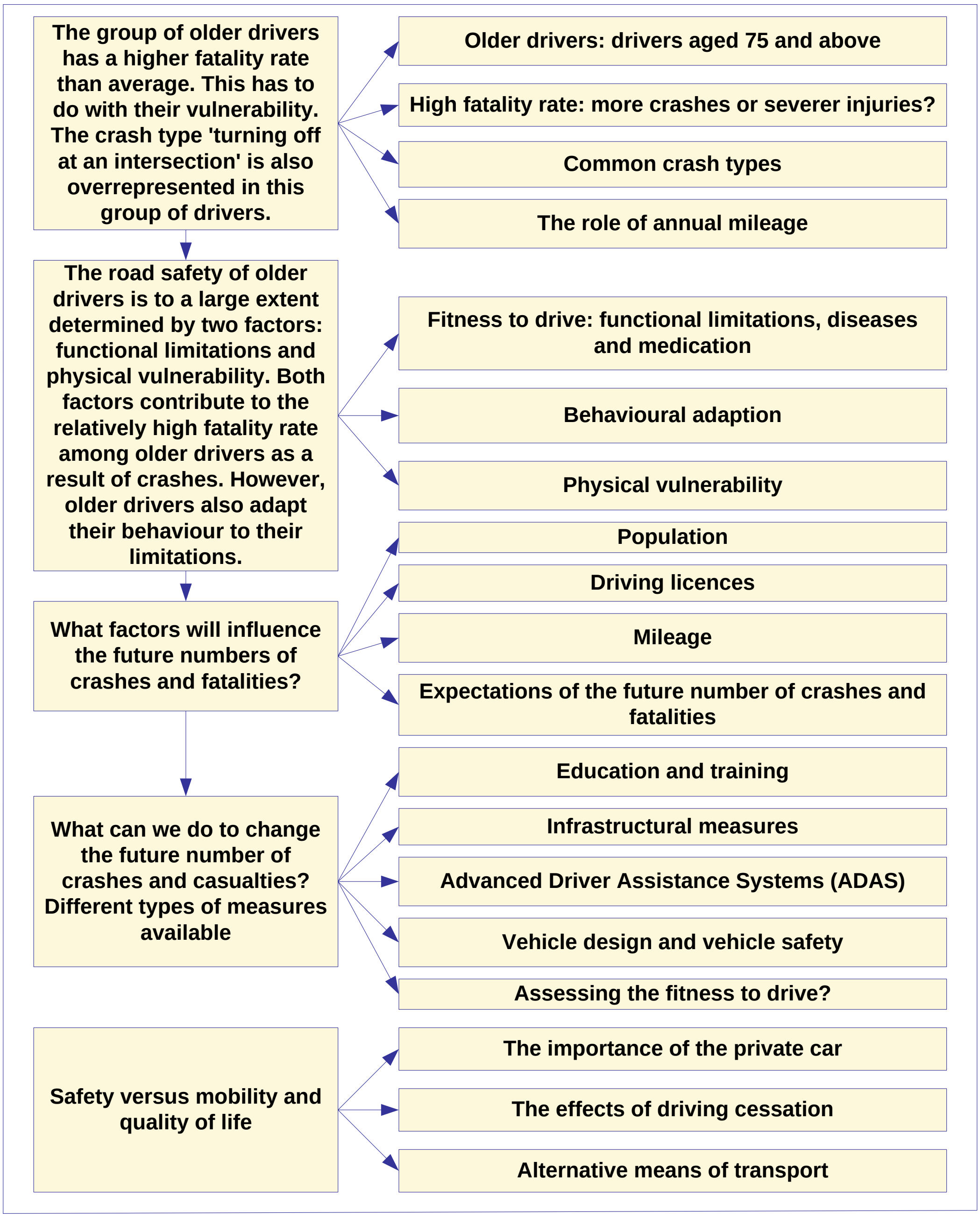

Who is at risk?

Older drivers (drivers aged 75 years and above) have the second highest fatility rate of all age-groups. At the same time, they are not so much a risk to others, but they are at risk themselves due to their frailty and vulnerability to the personal injury or risk of death in the event of a road traffic crash (OECD, 2004). As a result, older drivers have a relatively high fatality rate, but their injury rate is much lower. Data from the Netherlands illustrates this: the fatality rate (over distance) for car drivers aged 75 years and over is more than 5 times higher than for the average for all ages, whereas their injury rate is 2 times higher. The conclusion that the older driver is not a danger to others should not limit the development of road safety measures targeting older drivers. Nor can the claim be made that all drivers are sufficiently safe to continue driving. This depends on the physical and mental condition of the individual.

Older drivers are over-represented in side-impacts at intersections, where typically the older driver turns against oncoming traffic with right of way on the main road. Countermeasures need to target this crash type which will become increasingly common as the population ages. Older drivers are under-represented in crashes involving loss of control or collisions due to speeding, risky overtaking or driving under the influence of alcohol.

Functional limitations and physical vulnerability

The road safety of older road users is to a large extent determined by three factors, the main ones being functional limitations and physical vulnerability which both contribute to the relatively high fatality rate for older road users in road crashes. Functional limitations can increase crash risk, whereas higher physical vulnerability increases injury severity. A third reason for the high fatality rate of older adults seems to be their low annual mileage. In general, drivers travelling fewer kilometres have higher crash rates per kilometre compared to those driving more kilometres (“low mileage bias”, see e.g. Janke, 1991; Hakamies, Raitanen & O’Neill, 2002). These three explanations for the high fatality rate for older drivers are most probably connected, with the physical and mental condition of the driver having the greatest influence on the other two factors. That is, drivers who have a medical condition are also likely to be more fragile than other (older) drivers and will also drive less frequently or at least drive shorter distances.

As road users age - a process that starts at different times depending on the individual - functional limitations and disorders occur which may increase their road traffic crash rate. This is particularly the case in the decline of motor functions such as muscle strength, finely tuned coordination and the ability to adapt to sudden changes in bodily position. There are few indications that a decline in visual and cognitive functions, as part of normal ageing, also has road safety consequences. Only in the case of severe sensory, perceptual, and cognitive limitations does the relation between functional limitations and crash involvement become visible. Examples are eye disorders such as cataract, macular degeneration, and glaucoma, and diseases like dementia, stroke and diabetes.

Functional limitations and age-related disorders do not automatically lead to unsafe traffic behaviour since older road user behaviour and other characteristics often prevents road safety problems. These include being aware of one's limitations, long-driving experience, and compensation behaviour such as driving when the roads are less busy or when it is daytime and dry. However, notwithstanding behavioural compensation, once a crash occurs, older drivers are more vulnerable than younger drivers and their injuries will be more severe given any given impact.

Factors that will influence future developments

Various factors can influence the future developments in the number of fatalities among older drivers. These factors can be divided into autonomous factors and road safety measures. Examples of autonomous factors are the age composition of the population, the number of older adult driving licence holders, their mobility, and their driving experience. If these factors change over time they will influence the future number of fatalities among older drivers.

Increases in the number of people aged 75 years and above, in rates of licensed older drivers and in the mobility of older drivers will increase older driver fatalities. However, these increases will be ameliorated by reduced fatality rates as older drivers become more vital and experienced than those of today. Road safety measures can further reduce the fatality rate of older drivers into the future. Examples of measures are described in the next section. More information on older pedestrians and cyclists can be found in the ERSO web text on Pedestrians and Cyclists.

Measures that can reduce future fatality rates

Several types of measures are available to influence the future number of fatalities amongst older drivers. Given the physical vulnerability of older drivers, measures are needed that can reduce injury severity, such as improvements in active and passive vehicle safety. Measures that can reduce the older driver crash involvement also contribute to a reduction of their fatality rate. Examples of the latter type of measures include changes to road infrastructure, driver assistance systems, and providing education and training. In the case of a progressive decline of functions, training and adaptation of the infrastructure and the vehicle can no longer compensate for reduced fitness to drive. Therefore, in addition, a procedure is needed that will lead to a timely cessation of the driving career. Such measures involve licensing procedures and consultation of the medical profession regarding fitness to drive.

Safety versus mobility and quality of life

The introduction of driving test requirements which result in older drivers losing their driving licence when they can still drive a car safely is undesirable for a variety of reasons. Firstly, the fatality rate for older cyclists and pedestrians is many times greater than that for older car drivers. Consequently, they are safer in a car. In addition, older people often will have stopped cycling, partly because of loss of balance. Saying farewell to their car often is also a farewell to part of their social lives. As a result, the loss of driving privileges can cause considerable distress and a lowering of self-esteem and dignity, as well as create difficulties for daily activities, shopping and social contact.

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The availability of a means of transport other than the car is one of the most important ways to maintain older people's mobility. However, no single form of transport provides mobility for all people under all circumstances. Therefore, a variety of services is needed that enables travellers to select the one that best suits their requirements for a particular journey. These services include: public transport services including bus service routes, taxis, and the Dial-a-Ride service; an appropriate bicycle infrastructure and an accessible pedestrian infrastructure for journeys on foot or by wheelchair or scooter.

2 Older drivers: Risky or at risk?

Older drivers are often characterized as a group that has a high fatality rate in traffic. This high fatality rate can be caused both by increased crash involvement and by increased injury severity. However, older drivers, that is those aged 75 and above are very diverse, in their driving skills as well as in their physical and mental abilities. One thing that they do have in common is their low annual mileage. The latter may influence their crash rate, since drivers travelling fewer kilometres have increased crash rates per kilometre compared to those driving more kilometres. In addition, they generally drive less on motorways (with interchanges), the safest types of roads, and tend to drive on streets with intersections, which are, by their very nature, less safe. This is reflected in the crash types that are common among older drivers. Older drivers are over-represented in crashes at intersections, where typically the older driver turns against oncoming traffic with right of way on the main road.

2.1 Older adult drivers: drivers aged 75 and above

In general, the age-group referred to as older adult drivers is the one of 75 years and above. Previously, it was those aged 65 years and above. The reason for this shift in age-group is that older people are becoming more vital. Today's 75 year-olds are as vital as 65 year-olds were in the past and this is reflected in their fatality rate. Nevertheless, using rigid age boundaries does not take into consideration the fact that ageing is a process that does not start at the same age for each and every individual, nor progresses at the same pace. There can be large differences in driving skills between people of the same age, as well as in their physical and mental abilities. Some 85 year-olds may well be in better shape than some 40 year-olds.

2.2 High fatality rate: more crashes or more severe injuries?

Older drivers have a relatively high fatality rate. Data from the Netherlands illustrates this: taking distance travelled into account, the fatality rate for car drivers is seven times higher for those aged 75 years and older than for the average for all ages. The fatality rate of the 65 to 74-year-olds age-group is much lower. However, other means of independent transport are not safer. The fatality rate is particularly high for older cyclists. This rate is about 10 times higher for cyclists aged 75 years and older than for 'the average for all ages'. Compared with the fit group of 30 to 49-year-olds, the difference is even larger (see Table 1).

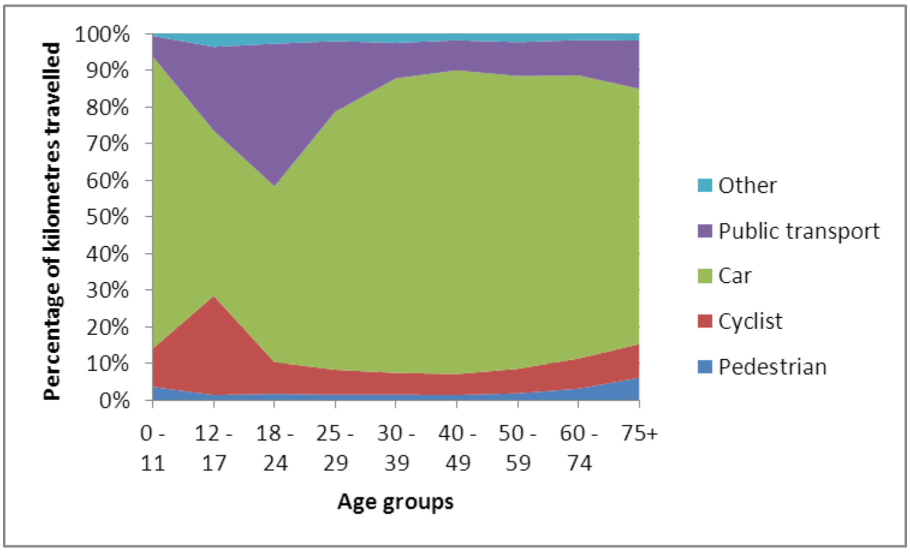
Table 1: Fatality rate: traffic fatalities per billion kilometres travelled, by age and mode of transport, Netherlands (2005-2009)

	Pedestrians	Cyclists	Car drivers	Car passengers
18 - 24	21	6	11	6
30 - 49	11	4	2	1
60 - 64	10	12	1	1
65 - 74	22	28	3	3
75+	97	124	14	9
All ages (18+)	20	12	2	2

Source: Ministry of Infrastructure and the Environment, Statistics Netherlands

Unfortunately, cross-national comparisons at this level of detail (fatality rate by age and mode of transport) are not possible. The international databases that contain crash data of several European countries do not include data on fatalities per means of transport per age-group. Cross-national comparisons of the number of fatalities and of fatality rates for all road users aged 65 years and above (regardless of means of transport) can be found in ERSO statistics Traffic Safety Basic Facts 2011: The Elderly (Aged >64).
The mobility patterns of older people are fairly comparable to those of younger persons. In all age-groups between 30 and 59, about 80% of all kilometres are travelled by car. After the age of 60, the percentage gradually reduces to 70%. In the Netherlands (2009), there is a shift to walking (total of 6% for people aged 75 and above), cycling (total of 9%) and public transport (total of 13%; See Figure 1).

Figure 1: Distance travelled by different modes by age-group in the Netherlands, 2009



Source: Statistics Netherlands / Ministry of Infrastructure and the Environment

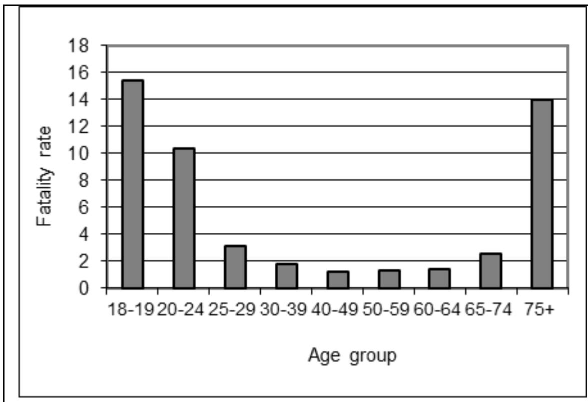
Note, however, that the occurrence of a traffic conflict or crash is also dependent on the possibility of meeting other traffic (traffic density and segregation of traffic modes) and on time spent in traffic. The value of the latter type of exposure varies greatly depending on the transport mode chosen to travel a certain amount of kilometres. Unfortunately, there are no recent national or European data available to illustrate the effects of the abovementioned factors on fatality rate per transport mode and/or age.

High fatality rates can be caused either by higher crash rates or by greater physical vulnerability. The vulnerability of a group of road users is reflected in the difference between their fatality rate and injury rate, but also in their fatality ratio: the percentage of fatalities in the total number of casualties.

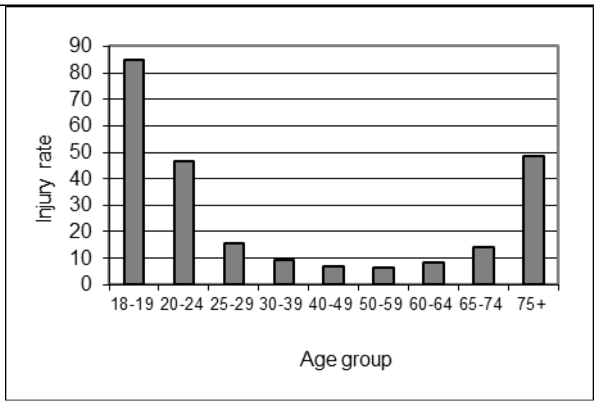
2.2.1 Fatality rate versus injury rate for different age-groups

Older drivers have the second highest fatality rate. Only the youngest group of drivers (18- and 19-year olds) has a higher fatality rate. The left side of Figure 2 shows the well-known U-shape: fatality rates of the young drivers are high, after which the rate declines to a minimum for drivers of the age of 40-60 years. Then it increases again, to a maximum for those aged 75 and older. The injury rates in Figure 2 (right side) also show a U-shape but they level off at the oldest age group. Whereas young drivers (18-24 years old) have a relatively high injury rate as well as a high fatality rate, the injury rate for older drivers is much lower than their fatality rate.

Figure 2: Fatality and injury rates per billion kilometres travelled by age, Netherlands 2005-2009



Fatality rate: traffic fatalities among drivers per billion kilometres travelled by age, Netherlands (2005-2009).



Injury rate: non-fatal seriously injured in-patients among drivers per billion kilometres travelled, by age, Netherlands (2005-2009).

Source: Ministry of Infrastructure and the Environment, Statistics Netherlands

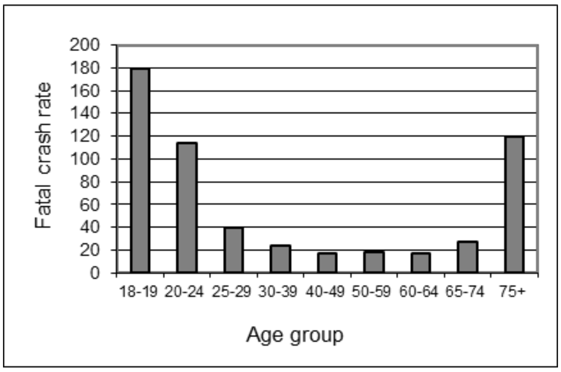
To explain this difference between young and older drivers, data is needed on the two underlying aspects of both rates: crash involvement and physical vulnerability. Crash involvement indicates how often a particular group of road users is involved in a crash (of a particular severity), without giving insight in the injury of the group of road users concerned (see Section 2.2.2). Physical vulnerability indicates the average injury severity of a particular group of road users (see Section 2.2.3).

2.2.2 Crash rate of older drivers in comparison with other age-groups

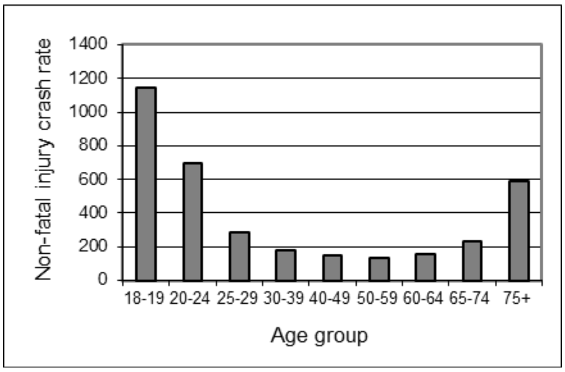
A comparison of the *crash rates* for fatal and non-fatal serious injury crashes for different age-groups shows that the youngest group of drivers is much more often involved in these types of crashes than other age-groups (see Figure 3). The group of drivers aged 75 and above has the second and third highest crash rate for fatal and non-fatal injury crashes respectively. However, the difference between the fatal crash rate for the youngest and that for the oldest group is much larger than the difference between their fatality rates. Therefore, it seems that the fatality rate of young drivers is influenced more by their crash involvement than is the case for those aged 75 and above. The high fatality rate of the latter age-group is probably determined to a larger extent by their physical vulnerability.

A confounding factor in the relationship between crash involvement and fatality rate is crash type. Some age-groups may have crashes that typically have greater impact, such as running off the road or crashes while driving at a higher speed. Driver behaviour also plays a role here. Older people, on average, drink and drive less often than younger adults and generally obey the traffic rules more often (Brouwer et al., 1988; Hakamies-Blomqvist 1994a).

Figure 3: Fatal and serious injury crash rates per billion kilometres travelled by age, Netherlands 2005-2009



Crash rate for fatal crashes: number of drivers involved in fatal crashes per billion kilometres travelled by age, Netherlands (2005-2009).



Crash rate for non-fatal serious injury crashes: number of drivers involved in non-fatal serious injury crashes per billion kilometres travelled by age, Netherlands (2005-2009).

Source: Ministry of Infrastructure and the Environment, Statistics Netherlands

2.2.3 Fatality ratio of older drivers in comparison with other age-groups

Fragility can be expressed as the number of fatalities per 100 injured victims or as the percentage of fatalities in the total number of casualties. The latter is called the fatality ratio (Mitchell, 2000). This ratio increases with age and is higher for unprotected road users such as pedestrians (see Figure 4 and Section 3.3 on Physical vulnerability).

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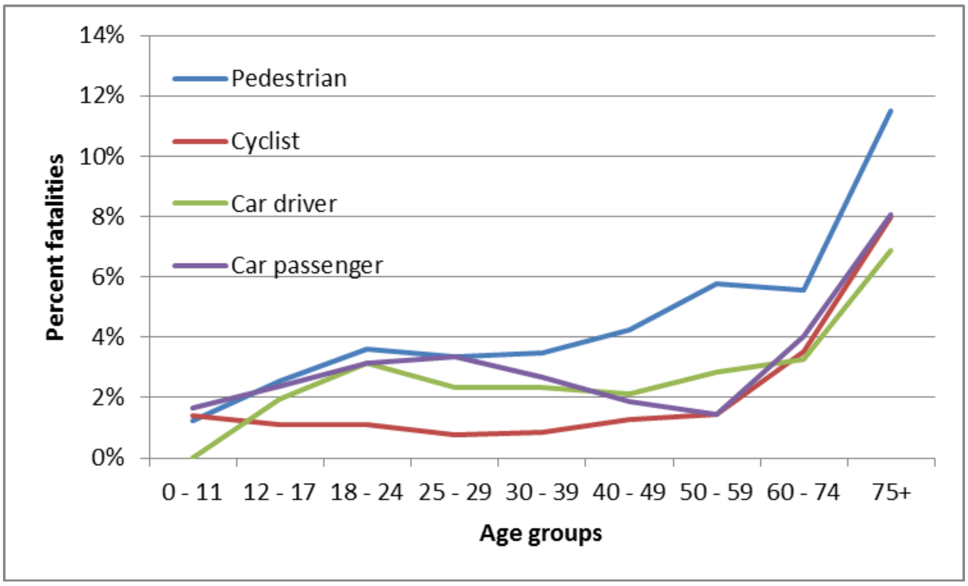
Figure 4: Fatality ratio: percentage of all injuries reported by police that are fatal, by age and means of transport, Netherlands (2005-2009)



Source: Ministry of Infrastructure and the Environment

2.3 Common crash types among older drivers

Various crash studies and surveys have shown that older drivers are over-represented in crashes at intersections, where older drivers typically turn against oncoming traffic with right of way on the main road (Hakamies-Blomqvist, 1993, 1994b; Zhang et al., 1998; McGwin & Brown, 1999; Davidse, 2000; OECD, 2001). In general, intersections represent complicated traffic situations which involve time pressure and the necessity of dividing attention between various sub-tasks (Brouwer & Ponds, 1994). Negotiating an intersection represents a “testing of the limits” type of task, since it combines a host of age-sensitive functions while simultaneously limiting the usefulness of normal safe driving strategies. Therefore, it seems plausible that the individual’s increased risk is related to the combined deterioration of a number of relevant perceptual and cognitive functions rather than to the deterioration of single functions (OECD, 2001).

Older drivers are under-represented in crashes involving loss of control, speeding, risky overtaking or driving under the influence of alcohol (Hakamies-Blomqvist, 1993, 1994b, 2003; McGwin & Brown, 1999; OECD 2001). This suggests that they are more aware of the risks associated with speeding and drinking and driving, and are more willing to avoid these kinds of risk-taking behaviour (see also Section 3.2 on Behavioural adaptation).

2.4 Role of annual mileage

Older drivers typically drive a shorter distance per trip and hence have lower annual accumulated driving distances. In general, drivers travelling more kilometres have reduced crash rates per kilometre compared to those driving fewer kilometres. Therefore, the low mileage of older drivers may exaggerate older driver risk per kilometre estimates (Janke, 1991). Several studies, using data from different countries, have tested this hypothesis (Hakamies-Blomqvist, Raitanen & O'Neill, 2002; Fontaine, 2003; Holte, 2005; Langford, Methorst & Hakamies-Blomqvist, 2006). They all found that when driver groups were matched for annual mileage, age-related increases in crash rates per kilometre travelled disappeared. That is, older drivers with an average or high annual mileage have crash rates that are comparable to those of younger adult drivers with the same annual mileage. Only drivers with a low annual mileage have more crashes per million driver kilometres, but this is the case for younger drivers as well as for older drivers.

Crash rates can also be biased by the type of roads typically travelled by older drivers. Many avoid driving on motorways, the safest types of roads, and tend to drive on streets with intersections, which are, by their very nature, less safe and where more crashes occur (Janke, 1991). Hence, older drivers' risk estimates based on injuries or fatalities per distance driven will be overestimated when compared to those of younger drivers with higher annual mileage on safer roads (OECD, 2001).

3 Functional limitations and physical vulnerability

The road safety of older road users is to a large extent determined by functional limitations and physical vulnerability. Both factors contribute to the relatively high fatality rate as a result of crashes among older road users. Functional limitations can increase crash risk, whereas a higher physical vulnerability increases injury severity. Functional limitations and age-related disorders do not automatically lead to unsafe traffic behaviour. Other characteristics of older road users can prevent safety problems. Among these are the insight into one's own limitations, driving experience, and compensation behaviour such as driving when the roads are less busy or when it is daytime and dry.

3.1 Functional limitations, diseases and medication

As people age, functional limitations and disorders occur that can increase the crash rate of road users. This is particularly the case in the decline of motor functions such as muscle strength, finely-tuned coordination and the ability to adapt to sudden changes in bodily position. There are few indications that a decline in visual and cognitive functions, as part of normal ageing, road safety consequences. Only in the case of severe sensory, perceptual, and cognitive limitations does the relation between functional limitations and crash involvement become evident (Brouwer & Davidse, 2002). Examples are eye disorders such as cataract, macular degeneration, and glaucoma and diseases like dementia, stroke, and diabetes. In considering whether to advise the restriction or suspension of driving licences or for prescriptions, the end functional capacity is the main concern, rather than individual sources of functional loss. The main issue is the severity of impact of all combined effects, and importantly, one needs to consider how much compensatory potential the older driver may have, to compensate for a particular deficit (Holland, Handley & Feetam, 2003).The relative risks of being involved in crashes due to a medical condition like diabetes or a vision impairment have been calculated in the EU-project IMMORTAL (Vaa, 2003). The results of these calculations are shown in Table 2. The significance of these health impairments for the total number of crashes depends on their prevalence in the population (Elvik, Hoye, Vaa, & Sorensen, 2009; Vlakveld & Davidse, 2011). Descriptions and prevalence of the medical conditions mentioned in Table 2 can be found in the next sections on age-related functional limitations, age-related disorders and medication.

Table 2: Relative risks of selected medical conditions

Medical condition	*Relative risk**	*95% Confidence Interval*	*Number of results*
Vision impairment (all types)	1.09**	(1.04; 1.15)	79
- Field of vision	0.90	(0.69; 1.17)	4
- Progressive eye diseases	0.86	(0.50; 1.49)	4
- Binocular visual acuity	1.13**	(1.05; 1.22)	39
Hearing impairment	1.19**	(1.02;1.40)	5
Arthritis/Locomotor disability	1.17**	(1.00;1.36)	12
Cardiovascular diseases (all types)	1.23**	(1.09;1.38)	48
- (Serious) arrhythmia	1.27**	(1.09; 1.47)	14
- Abnormal arterial blood pressure	1.03	(0.86; 1.22)	8
- Suffering from angina	1.52**	(1.10; 2.09)	3
- Myocardial infarction	1.09	(0.62; 1.92)	2
Diabetes mellitus	1.56**	(1.31;1.86)	25
Neurological diseases (all types)	1.75**	(1.61;1.89)	22
- Diseases affecting central nervous system (e.g. stroke, Parkinson's disease)	1.35**	(1.08; 1.67)	11
- Epilepsy/other seizures	1.84**	(1.68; 2.02)	8
Mental disorders (all types)	1.72**	(1.48;1.99)	33
- Dementia	1.45**	(1.14; 1.84)	18
Alcoholism	2.00**	(1.89; 2.12)	3
Drugs and medicines	1.58**	(1.45; 1.73)	68
Renal disorders	0.87	(0.54; 1.34)	3
Weighted average across all main groups	1.33**	(1.28; 1.37)	298
* A relative risk of 1.09 means that drivers with the mentioned medical condition have a 9% higher crash rate than drivers without any medical condition. ** The relative risk is statistically significant at a level of α < 0.05			

Source: Vaa, 2003

3.1.1 Age-related functional limitations and their relevance to road safety

As drivers age, information processing capacities generally decline. However, individual differences are large, not only in terms of the chronological age at which the ageing process manifests itself, but also in terms of the pace at which the ageing process continues. Several traffic-related studies have given an overview of the specific sensory, cognitive, and motor skills that deteriorate with age (Holland, 2001; Maycock, 1997; Sivak et al., 1995). The most important functional changes that accompany normal ageing relate to:

- Visual and perceptual abilities
- Cognitive abilities
- Physical abilities

<u>Decline in vision and perceptual abilities</u>

The visual functions which decrease as people age are: visual acuity, peripheral vision, visual acuity in poor light and sensitivity to glare, contrast sensitivity, detection of movement, and colour vision (Shinar & Schieber, 1991; Klein, 1991; Sivak, 1995; Holland, 2001).

Decreases in visual acuity (the ability to see details) generally accelerate after the age of 50 (Corso, 1971). The decrease of visual acuity often occurs so slowly, that people do not notice their visual acuity becoming worse and people therefore often overestimate their visual powers. In many cases, the visual acuity of drivers is below the legal standard, without their knowing it. Good visual acuity is not only important for the perception of traffic signs and signals, but also for long-distance sight that is specifically needed for overtaking on secondary roads (Groot, 1999).

The visual field determines to what extent objects and events situated outside the fixation point are perceptible. Adequate peripheral vision is one of the most important prerequisites for safe driving. The driver has to see cars in adjacent lanes when making a lane change, to keep the car centered in its lane; to see a pedestrian leaving the pavement or to see another car approaching an intersection. Defects in peripheral vision typically occur in patients with glaucoma (increased eye pressure), macular degeneration, diabetes, and after stroke or other cerebral diseases (Groot, 1999). These diseases are found more often amongst older drivers).

Functional impairments relevant for driving in the dark are night-time visual acuity and sensitivity to glare. Impaired nighttime visual acuity is the result of two age-related changes that reduce the amount of light reaching the retina: reduced pupil size and yellowing of the lens (Olson, Sivak & Egan, 1983). A consequence of reduced retinal illumination is that sources must be of higher intensity to be seen at night (Olson, Sivak & Egan, 1983). However, older adults' increased vulnerability to disability glare makes it important to assure that lighting is appropriately directed (Kline & Scialfa, 1997): sensitivity to glare, which increases between the ages of 40 and 70, leads to a slower recovery from headlights and other reflecting sources (Fozard et al., 1977; cited in Aizenberg & McKenzie, 1997). Cataract is one of the main causes of sensitivity to glare among older people (Groot, 1999).

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As far as contrast sensitivity is concerned, older adults have more trouble discerning small details and this becomes worse at low illumination levels. Contrast sensitivity is – even more than visual acuity – necessary for the perception of (the information on) traffic signs. Besides this, contrast sensitivity is also believed to play a role in distance perception and the estimation of the speed of moving objects (Shinar & Schieber,1991; Holland, 2001).

The age-related changes in colour vision relevant to driving also concern contrast. Older adults have problems discriminating between blue, blue-green and violet: not important colours for the perception of traffic signs and signals. However, older adults also have problems discriminating between colours that are very much alike. Therefore, the differences between colours used in displays of Intelligent Transportation Systems should be as pronounced as possible (Holland, 2001).

Detection of movement decreases with increasing age. This is as a result of age-related changes to neural mechanisms and a less smooth movement of the oculomotor system which results from the ageing process. Obviously, the ability to detect movement is very important for safe driving, not only to detect vehicles approaching from the sideand to estimate their speed, but also to detect changes in the speed of the vehicles ahead, i.e. stopping, slowing down, speeding up, and reversing (Shinar & Schieber,1991; Holland, 2001).

<u>Declines in cognitive abilities</u>

Age-related decreases in sensory abilities such as vision have an impact on the input the driver receives from other road users and the infrastructure. To select the appropriate information, interpret it and make decisions which must then be translated into an appropriate driving action, one needs perceptual and cognitive processes. Some of these processes decline as people grow older, including the ability to maintain attention over longer periods of time, the ability to separate important from unimportant information (selective attention), the ability to share attention between various tasks (divided attention), short-term memory and information-processing speed (Maycock ,1997).

Speed of processing information is often crucial to making safe decisions in driving. Fundamental to this aspect of the driving task is the time taken by a driver to respond to the demands placed upon him or her by the traffic environment (often referred to as the 'perception-reaction' time). Research studies have generally found that reaction times to simple stimuli do not deteriorate dramatically with age (Olson & Sivak, 1986). Reaction times of older drivers only increase when drivers have to make decisions in complex situations (Quimby & Watts, 1981).

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Physical changes
Physical abilities that decline as people age are joint flexibility, muscular strength, and 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 recovery (Sivak et al., 1995).
An example of the influence of reduced joint flexibility is that reduced neck rotation can hinder the driver while checking for approaching traffic at intersections or before merging. This is especially detrimental to older drivers, since they rely on neck rotation to compensate for their restricted visual field. Decline in joint flexibility is not the same for all body parts. In a study by Kuhlman (1993), older adults had approximately 12% less cervical flexion, 32% less neck extension, 22% less lateral flexion and 25% less rotation than the younger control group (Sivak et al., 1995). Joint flexibility can be greatly influenced by degenerative diseases such as arthritis, which is experienced to some degree by approximately half the population over 75 (Adams & Collins, 1987; cited in Sivak et al., 1995). The crash risk associated with diseases such as arthritis can be found in the Table of relative risks (Vaa, 2003).

3.1.2 Age-related disorders that can restrict fitness to drive

A number of diseases and disorders are found to be related to crash proneness. These are: eye disorders, dementia, Parkinson's disease, stroke, cardiovascular diseases and diabetes. These diseases and disorders can occur at all ages, but they are more common among older adults. Comorbidity, which means having more than one disease, is also more common among older adults. Specific crash risks associated with age-related disorders can be found in the Table of relative risks (Vaa, 2003). It should be noted, however, that increased risks can also be caused by the medications that are being taken because of one or more disorders.

Eye disorders
The eye disorders cataract, macular degeneration, glaucoma, and diabetic retinopathy are the leading causes of a significant decline in visual acuity and visual field while ageing (Klein, 1991). The crash risks associated with eye disorders can be found in the Table of relative risks (Vaa, 2003). Cataract is characterized by a clouding of the eye lens and affects glare sensitivity, colour perception and night vision. Fortunately, it can be treated by replacing the lens with an artificial one. Age-related macular degeneration is a disorder of the central part of the retina and affects visual acuity and colour perception. This disorder, therefore, can lead to the inability to read road signs or to see cars. Glaucoma affects the peripheral part of the retina as a result of damages caused by high intraocular pressure. This condition is painless and the patient is often unaware of the deficit in visual field, a deficit which causes difficulties seeing cars or pedestrians approaching from the side (Klein, 1991). Persons with diabetes, a disease that affects between 10% and 20% of the older adults (Harris, Hadden, Knowler & Bennett; cited in Klein, 1991), are at higher risk of developing cataract, glaucoma and abnormalities that affect the retinal blood vessels (diabetic retinopathy). The latter often result in deficits in the peripheral visual field.

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Dementia

Dementia is a syndrome that is characterized by a progressive decline of cognitive functions as a result of brain damage or illness. The most common illness which leads to this syndrome is Alzheimer's disease, accounting for approximately half of all dementia cases. Alzheimer's disease is characterized by impairments in memory and at least one other cognitive domain, such as attention or judgement. The exact impairments depend on the areas of the brain that are affected.

Dementia often involves a poor understanding of one's own illness, as a result of which patients are often not capable of judging their own limitations and of adapting their behaviour accordingly. Thus, drivers with dementia are less likely to limit their exposure to high-risk situations than drivers who have diminished visual and physical abilities, but intact cognitive abilities (Staplin et al., 1999). The mere diagnosis of dementia is not enough to advise older adults to stop driving. According to an international consensus group on dementia and driving, drivers should be advised to stop driving when they are diagnosed with moderate or severe dementia. When continued driving is considered permissible, it is of great importance to ensure regular follow-up examinations (Lundberg, 1997). The crash risk associated with dementia can be found in the Table of relative risks (Vaa, 2003). Estimates of the prevalence of dementia in the total group of people over 65 years of age vary from 5% to 15%.

Parkinson's disease

Parkinson's disease is a progressive, age-associated neurological syndrome that is primarily due to the insufficient formation and action of dopamine. Patients suffer from resting tremor, stiffness, the inability to initiate movements (akinesia), and impaired postural reflexes. In addition, Parkinson's disease is associated with depression and dementia at rates much higher than age-related norms. Estimates of the prevalence of dementia in people with Parkinson's disease range from 30% to 80% (Kaszniak, 1986; cited in Holland, Handley & Feetam, 2003), whereas estimates of the frequency of dementia in the total group of people over 65 years of age vary from 5% to 15%.

Both the movement and cognitive effects of Parkinson's disease have potentially important implications for the patient as a driver. However, as in other chronic diseases, the level of function is a more important criterion for fitness to drive than the diagnosis of Parkinson's disease itself. Most people with severe Parkinson's disease give up driving (Holland, Handley & Feetam, 2003).

One particular area of concern relating to driving and Parkinson's disease is the occurrence of excessive sleepiness that is common in this disease. A study by Frucht (cited in Holland, Handley & Feetam, 2003), showed that excessive sleepiness was prevalent in 51% of the study participants. This sleepiness correlated with severity and duration of Parkinson's disease and risk of falling asleep at the wheel. The use of anti-Parkinson (dopaminergic) drugs also seems to contribute to the excessive sleepiness (Fabbrini et al., 2002; cited in Holland, Handley & Feetam, 2003). The crash risk associated with Parkinson's' disease can be found in the Table of relative risks (Vaa, 2003).

Stroke

A stroke, also known as cerebrovascular accident (CVA), is a neurological injury whereby the blood supply to a part of the brain is interrupted, either by a clot in the artery or by a burst of the artery. Driving after a stroke is problematic if there are cognitive changes, even assuming that the patient is rehabilitated enough to manage the driving task. Many people do not resume driving after a stroke. Those who stop driving are generally older and/or have other sources of impairment or disability in addition to the effects of their stroke (Holland, Handley & Feetam, 2003). Little research has been done into the effects of a stroke on fitness to drive. In general, it is assumed that effects of a stroke on motor performance, such as paralysis, can be compensated for by vehicle adaptations and retraining. Other effects, such as apraxia (lack of ability to imagine, initiate or perform an intended action) and lateral neglect, have more severe consequences. In the case of lateral neglect, which means that the patient does not react to or look at things that are located on one side of the visual field (the side opposite to the affected hemisphere), people should be advised to stop driving (Brouwer & Davidse, 2002). A study in which driving of left-sided and right-sided stroke victims and controls were compared, showed that the performance of those with right-sided brain damage was consistently poorer than that of those with left-sided damage. The former more frequently failed the driving test, and particularly performed more poorly at intersections (Simms, 1992). The crash risk associated with a stroke can be found in the Table of relative risks (Vaa, 2003).

Cardiovascular diseases

Cardiovascular diseases include diseases such as angina pectoris (chest pain), cardiac arrythmias, heart failure and hypertension (abnormally high blood pressure). Studies that have distinguished these different conditions have indicated that only cardiac arrythmias and angina pectoris increase crash risk. Actual heart attacks are only responsible for a small part of the total relationship of cardiovascular illness with driving risk (Holland, Handley & Feetam, 2003). The crash risks associated with cardiovascular diseases can be found in the Table of relative risks (Vaa, 2003).

Diabetes Mellitus

Diabetes is a disorder that is characterized by high blood sugar levels, especially after eating. The incidence of diabetes becomes much more common with increasing age, with 17-20% of 70-year-olds having difficulty regulating glucose as compared with 1.5% of 20-year-olds (Holland, Handley & Feetam, 2003). There are two types of diabetes: insulin dependent (type I) and non-insulin dependent (type II). The former are dependent on insulin injections, the latter can control blood sugar levels by diet, weight reduction, exercise and oral medication.

Estimates of the crash risk associated with diabetes used to be as high as twice the rate of average drivers. However, improved medications, better possibilities for diabetic patients to monitor their own blood glucose levels, and improved understanding of diabetic control seem to have reduced the crash risk (Hansotia, 1993; cited in Holland, Handley & Feetam, 2003).

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An important drawback of tighter control of blood glucose levels is that hypoglycaemic episodes are now much more common. During these episodes with low blood sugar levels, cognitive functions are diminished. Even with only modest levels of hypoglycaemia at times when individuals may be totally unaware that they are hypoglycaemic (Waller, 1992). All in all, serious diabetes (treated with oral drugs or with insulin) is still one of the strongest predictors of crashes, showing a stronger relationship than other illnesses examined (Holland, Handley & Feetam, 2003). The crash risk associated with diabetes can be found in the Table of relative risks (Vaa, 2003). Persons with diabetes are also at higher risk of developing the eye disorders cataract, glaucoma and abnormalities that affect the retinal blood vessels (diabetic retinopathy), all affecting visual acuity and visual field.

Comorbidity (more than one disease)
Many older adults suffer from more than one disease. In a study by Holte and Albrecht (2004) it was found that two out of three persons aged 60 years and above suffer from at least one illness. Nearly every second person suffers from more than one illness. Suffering from more than one disorder can reduce the driver's ability to compensate for the effects of these disorders. In addition, suffering from more than one disease often means that multiple medication has to be prescribed (polypharmacy), which increases the likelihood of pharmacokinetic or pharmacological interactions.

3.1.3 Medication

Regardless of the age of the patient, there is consensus on medications that present a risk to drivers. These are, among others, benzodiazepines, tricyclic and second generation antidepressants, painkillers that act on the peripheral and central nervous system (analgesics), and first generation antihistamines. Older patients, however, are likely to exhibit altered sensitivity to medication, and this should be taken into account when prescribing. This change usually involves an increased effect, including side-effects and adverse reactions, and the duration of action of a drug may be significantly prolonged. Since many older adults suffer from more than one disease, older patients are also more likely to be prescribed multiple medication (polypharmacy). The wider variety of medications being taken, the greater the likelihood of pharmacokinetic or pharmacological interactions. Medicines which are not prescribed but that can be obtained over-the-counter can add to this effect (Holland, Handley & Feetam, 2003).

In evaluating the possible impact of a medication on driving, it is important to remember that medication is prescribed for an illness, and that the illness may itself affect driving-related abilities. A particular medication could affect driving independently, it could increase any deterioration in driving ability caused by the illness, or it could even act to reduce the risk to the patient caused by the illness. The issue is not whether the specific drug has an effect on driving performance, but rather, whether the individuals are capable of functioning safely in their environment (Holland, Handley & Feetam, 2003).

3.2 Behavioural adaptation

Functional limitations and age-related disorders do not automatically lead to unsafe traffic behaviour. But other characteristics of older road users can prevent safety problems. They include insight into one's limitations, long driving experience, and compensatory behaviour. There are various reasons why older people have more opportunities to compensate. Firstly, they often have more freedom in choosing when to travel. Various studies have shown that older people more often choose to drive during daytime and dry weather. In the second place older people on average have a great deal of driving experience. The traffic insights they have acquired may give them the ability to anticipate possible problematic situations. In the third place, the diminishing desire for excitement and sensation when getting older possibly plays a role. In line with this, older people, on average, drink and drive less often than younger adults and generally obey the traffic rules more frequently (Brouwer, Rothengatter & Van Woffelaar,1988; Hakamies-Blomqvist 1994a).

With regard to compensation for functional limitations, Jansen et al. (2001) identified four different compensation styles among older drivers which account for 84% of their study participants (the compensation styles of the remaining 16% could not be identified):

- Functional compensation (23.4%): people are aware of their deficits and report adequate changes of driving behaviour.
- Dysfunctional compensation (5, 5%): people are aware of their deficits, but do not report adequate changes of driving behaviour.
- Preventive behaviour (24, 9%): people are not aware of their deficits, but they report adequate changes of driving behaviour.
- Missing compensation (30 %): people are not aware of their deficits, and they do not report adequate changes of driving behaviour.

Possibilities for compensatory behaviour

According to the hierarchic structure of the driving task proposed by Michon (1971; 1985), there are three levels of skill and control: strategic, tactical and operational. Possibilities for compensatory behaviour are offered especially at the higher levels of control. At these higher levels (strategic and tactical), there is hardly any pressure of time, giving the driver enough time to make the right decisions. Examples of the kind of decisions that are made at the strategic level are “when and how to drive to a certain destination”. At the tactical level, decisions are made on the distance that should be kept from the vehicle in front, and whether or not to overtake. At the operational level, only milliseconds are available for decisions on braking and steering. By deciding on a longer headway from the vehicle in front (at the tactical level), there will be more time to react and operate. Similarly, by reducing speed at the approach of an intersection, there will be more time to respond to the information given by the traffic environment.

3.3 Physical vulnerability

Older adults are more vulnerable than younger adults: their injuries will be more severe given the same impact. With the same impact force, the fatality rate is approximately three times higher for a 75 year old motor vehicle occupant than for an 18 year old (Evans, 1991, 2001) Physical vulnerability has the severest consequences during 'unprotected' journeys such as walking and cycling. This physical vulnerability is a less important factor for car drivers, but it still has an influence on injury severity. Physical vulnerability is mainly caused by age-related disorders such as osteoporosis (Mackay, 1988).

4 Factors influencing the future number of fatalities among older drivers

Various factors can lead to an increase or reduction of the current number of fatalities among older drivers. These factors can be divided into autonomous factors and road safety measures. Examples of autonomous factors are the age composition of the population, the number of driving licence holders, and mobility. If these factors change in the course of time, they will influence the future number of fatalities among older drivers. Road safety measures can be taken to reduce the fatality rate of older drivers in the future (see Section 5).

Another factor that might influence the future number of fatalities among older drivers could be the transition of older drivers from a minority group with special needs and habits to one of the largest sub-groups of drivers. This transition will probably affect the dynamics of the total traffic system, including the behaviour of other road users. The increasing probability of having to interact with an older driver may elicit profound changes in the behaviour of all drivers, as well as in patterns of interaction among the participants in the traffic system. As a result, the increasing participation of older drivers in traffic may lower the crash rates for older drivers (OECD, 2001).

4.1 Population

In most European countries, the number of older people has increased over the last decades. This increase will intensify in the next 20 years. Currently, 16% of the European population is aged 65 years or above, and 4% is aged 80 years and above. These percentages will increase up to 25% and 8% respectively in 2040 (Lanzieri, 2011). The percentage of people having difficulties in traffic due to functional limitations is clearly larger among the older group (80 and above) than among the younger group (65-79 years). This not only applies to older pedestrians and cyclists, but also to older drivers. As the group of older people becomes increasingly large, road safety policy will need to focus more on the safety needs of this group of road users.

4.2 Driving licences

In Europe, the percentage of licenced drivers in the group of drivers between the age of 65 and 74 years varies from 71 to 93% for men and from 7 to 46% for women (OECD, 2001). These groups of drivers represent the older drivers of tomorrow, those aged 75 years and above. Current licence rates for those aged 75 year old and above are considerably lower. For example, data from the 2009 travel survey of the Netherlands show that 90% of men and 63% of women aged between 65 and 74 years had a driving licence, whereas these rates are 75% and 18% respectively for those aged 75 years and above. Licence rates for women, in particular, have increased. Translating the licence rates for even younger age-groups to the future, and combining them with population data will provide estimates of the percentage of drivers aged 65 years and above in 2030. These figures show that in 2030, a quarter of all drivers will be aged 65 and above (see Table 3).

Table 3: Percentage increase in licensed drivers to 2030 for selected countries

Country	*Percentage of total number of licensed drivers aged 65+ in 2000*	*Percentage of total number of licensed drivers aged 65+ in 2030*	*Percentage increase in licensed drivers aged 65+*
Finland	14.9%	26.7%	79%
France	16.1%	25.8%	60%
Netherlands	13.7%	26.5%	93%
Norway	15.3%	23.5%	53%
Spain	16.8%	26.1%	55%
Sweden	17.2%	24.1%	40%
United Kingdom	15.7%	23.5%	49%

Source: OECD, 2001

4.3 Mileage

Expectations are that tomorrow's older driver will continue to drive longer and for larger distances than earlier cohorts, partly because they have better access to cars. In England, Sweden and Norway, the number of trips taken daily by older people (as well as by other age-groups) remained reasonably constant between 1985 and 2000, but the daily distance travelled increased (OECD, 2001). In the United States, the number and length of trips have increased for people over 65 years of age, with faster growth for older people than for other age-groups (Rosenbloom, 2000). Much of the increase in travel distance among older groups can be attributed to better access to a car. The car is becoming more dominant as a transport mode for older people, but there are differences among countries, especially between Europe and the United States. In Europe, walking is still an important transport mode for older people, with 30-50% of older people's trips made on foot. However, car use seems to be replacing walking and to a lesser extent, public transport (OECD, 2001), although there are differences between and even within countries, possibly influenced by town planning and access to cars and public transport (Mollenkopf et al., 2004; Bell et al., 2010). Differences are also observable between the young old and older old age-groups, with the younger age-groups using cars more frequently (Bell et al., 2010). Since there will be more older females with a driving licence in future, gender differences in car use among older people today may be reduced by 2030 (OECD, 2001).

4.4 Expectations of the future number of crashes and fatalities

Using population figures, data relating to the number of licensed drivers, data on the annual mileages they drive, and crash data, Maycock (2001) has forecast the number of fatalities and serious injuries among UK older driver groups for the period 1998-2022. The results of the forecasts show that during this period the number of fatal and serious casualties among older male drivers will decline, whereas the number of fatal and serious casualties among older female drivers will increase (see Table 4). The yearly rates of decline and increase differ by age-group: the older the age-group, the smaller the decline for male drivers and the larger the increase for female drivers. The increase of fatalities and serious injuries among older female drivers is caused by the expected future growth in the number of drivers in this group (see driving licences). These forecasts show that the number of casualties among older drivers will decrease less than the number of casualties among younger drivers, leading to a larger share of casualties among older drivers. The same trend was predicted for the Netherlands by Davidse (2000, 2007).

Table 4: Predicted yearly rates of increase or decrease of the number of fatal and serious casualties in the period 1998-2022 in the UK

	Male drivers	*Female drivers*
60-64	-3.5%	-2.0%
65-69	-4.0%	-1.8%
70-74	-3.1%	-0.8%
75-79	-2.9%	0.0%
80-84	-2.1%	0.9%
85-89	-1.6%	2.2%
90+	-0.8%	4.2%

Source: Maycock, 2001

5 Improving older driver safety

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 fatality rate among older road users as a result of crashes. Functional limitations can increase crash risk, whereas a higher physical vulnerability increases injury severity. Taking into account these causes of the high fatality rate among older drivers, a package of measures to reduce their fatality rate should include measures that are aimed at reducing injury severity as well as their crash involvement. Examples of measures aimed at reducing crash involvement are: infrastructural measures, driver assistance systems and providing education and training (Maycock, 1997; Hakamies-Blomqvist, Sirén & Davidse, 2004; Davidse, 2007). In the case of a progressive decline of functions, training and adaptations of the infrastructure and the vehicle can no longer compensate for reduced fitness to drive. Therefore, a procedure is needed that will lead to a timely cessation of the driving career. The availability of alternative means of transport will alleviate the pain of giving up driving (see Chapter 6). To sum up, to ensure the older adult's safety, a package of measures should be composed that includes all of the elements listed below:

- Infrastructural measures
- Advanced Driver Assistance Systems (ADAS)
- Vehicle design and vehicle safety
- Education and training
- Arguably assessing the fitness to drive

5.1 Infrastructural measures

An infrastructure that takes into account the functional limitations that accompany ageing can contribute to a reduction of the crash involvement of older people and is a key element of the recommended *Safe System* approach. This involves providing the older driver with enough time to observe, decide and act either by providing more time, or by making the driving task easier. Examples of infrastructural elements that provide enough time are long acceleration lanes on motorways and large stopping sight distances at intersections. Examples of infrastructural elements that make it easier to observe, decide and act, are an increased letter-height and retro-reflectivity of street name signs, and a higher contrast between pavement markings and the carriageway. Based on problems that older drivers encounter in traffic (see Box below), infrastructural measures should focus on (Staplin et al., 2001):

- Intersection design
- Road signs and markings
- Traffic lights and fixed lighting
- Exits and entries of motorways

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Which infrastructural elements create problems for older adult drivers?

With respect to infrastructural measures that might be able to improve the safety of older adult drivers, it is interesting to know what the older adults themselves indicate to be a problem. Benekohal et al. (1992) posed this question to a group of older adult drivers in the USA. Topics mentioned most were:

- Reading street signs in town
- Driving across an intersection
- Finding the beginning of a left-turn lane at an intersection
- Making a left turn at an intersection
- Following pavement markings and
- Responding to traffic signals.

The same group of researchers also gathered information about the highway features that become important to drivers as they age:

- Lighting at intersections;
- Pavement markings at intersections;
- Number of left-turn lanes at an intersection;
- Width of travel lanes;
- Concrete lane guides (raised channelisation) for turns at intersections; and
- Size of traffic signals at intersections.

Mesken (2002) posed similar questions to older adult drivers in the Netherlands. Traffic situations in the proximity of intersections that were most often mentioned as being difficult were:

- Making a left turn at an intersection without traffic lights
- Driving across an intersection without traffic lights and
- Driving round a roundabout which has more than one lane.

5.1.1 Intersection design

Several studies have revealed that crashes at intersections are over-represented among crashes involving at-fault drivers of 75 years and older (Hakamies-Blomqvist, 1993, 1994b, Zhang, 1988; McGwin & Brown, 1999; Davidse, 2000, 2007). Negotiating intersections requires complex judgements of speed and distance under pressure of time. Older adults generally have more trouble in meeting these requirements than do younger drivers. Functional limitations that are particularly related to these problems are an increased perception-reaction time and a decline in the ability to discriminate between relevant and irrelevant information. Besides this, a decrease in both visual acuity and mid-peripheral vision plays an important role in safely negotiating an intersection. Mid-peripheral vision is important to allow the sighting of a pedestrian getting ready to cross the street or to enable the driver to see another car approaching the intersection. Infrastructural measures that are important in this respect are:

- providing a good and early view on the intersection;
- assistance in making a left turn; and
- roundabouts.

View of the intersection

At the approach of an intersection, the view of other traffic approaching it is largely determined by the angle at which crossing streets meet. The optimal angle is one of 90 degrees. A smaller angle makes it more difficult to obtain an overview of the intersection and to notice other road users. Road users can compensate for these difficulties by minor changes to the position of their head. But since older adult road users generally have restricted head and neck mobility, they will experience more problems with intersections where streets meet at a reduced angle. Therefore, a right-angled junction is important for older adult road users. A secondary benefit of a right-angled junction is that it keeps the intersection area as small as possible, thereby reducing the chance of a crash.

Apart from the fact that older adult road users have more problems viewing the intersection because of restricted mobility of the head and neck, they also need more time to react (reduced perception-reaction time). A restricted view on the intersection, not only because of a small angle between the intersecting roads, but also as a result of shrubs, trees and buildings blocking the view on the intersection, leaves the driver little time to survey the intersection and little time to react. The resulting pressure of time causes more problems for older adult drivers than for younger drivers. Therefore, a restricted sight distance or stopping sight distance has more adverse consequences for older adult drivers than for younger drivers. This problem can be addressed by using a longer perception-reaction time when calculating the required sight triangle and the stopping sight distance, with a minimum of 2.5 seconds. A reduction of vehicle speeds at intersections is also helpful. This can be achieved by, for example, raising the intersection or replacing an intersection with a roundabout.

Assistance in making a left turn

As mentioned previously, older drivers are over-represented in crashes while turning left. These crashes often occur because drivers do not give way to traffic going straight ahead: they either estimate the speed of the approaching vehicle incorrectly, or have not seen it. These factors combine with the various functional limitations that accompany ageing, such as a decrease in depth and motion perception (necessary to determine speed and distance of approaching traffic) and a decline in divided and selective attention (the ability to share attention between various tasks and to separate important from unimportant information respectively). For intersections with traffic lights, errors in giving way and any resulting crashes can be prevented by a conflict free regulation: traffic that can collide does not get a green light simultaneously (for example, separate phases for traffic travelling straight on and traffic turning left). In such a case, road users never have to decide on whether it is safe to turn left.

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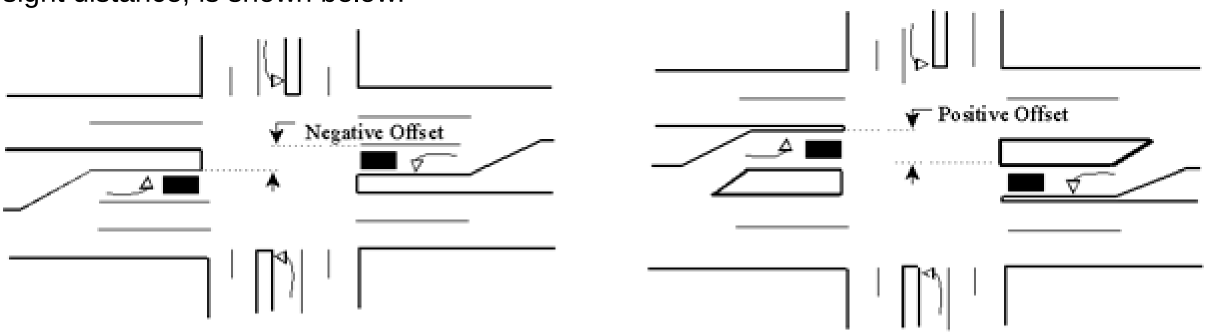
Intersections without traffic lights need to be designed to allow drivers to have an uninterrupted view of the traffic they must cross. Amongst other considerations, this means that two roads should preferably cross at right angles, that bushes and buildings do not obstruct the view, and also that drivers do not block each other's view (e.g. cars in the opposite left-turn lane waiting to turn left restricting the driver's view of oncoming traffic in the through lanes).This last situation can be prevented by offsetting the position of opposite left-turn lanes such that drivers facing each other do not obstruct each other's view (Staplin et al., 2001).

Positive offset of left-turn lanes

Opposite left-turn lanes and traffic using these can restrict the left-turning driver's view of oncoming traffic in the through lanes. The level of restricted view depends on how the opposite left-turn lanes are aligned with respect to each other, as well as the type/size of vehicle in the opposing queue. Restricted sight distance can be minimized or eliminated by shifting opposite left-turn lanes to the right (positive offset) so that left-turning drivers do not block each other's view of oncoming traffic. The difference between a negative offset of opposite left-turn lanes, which provides the worst sight on other traffic, and a positive offset, which provides the greatest sight distance, is shown below:



Source: Staplin et al., 2001

Roundabouts

Modern roundabouts have all the required qualities to compensate for the functional limitations of older drivers: left turns are completely eliminated, the driver has fewer decisions to make because of one-way traffic and yield-at-enter, lower speeds allow for more time to decide and act, and view on the intersection is not restricted by small angles between intersecting streets (Staplin et al., 2001; Davidse, 2000). For this reason, roundabouts are highly relevant for solving the problems that the older adult driver encounters when crossing intersections. All the more so, because roundabouts not only reduce crash numbers, but also, as a result of lower speeds, crash severity which is especially beneficial to improving the safety of older drivers.

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At the same time, there are several problems which need to be borne in mind. Firstly, roundabouts are relatively new to motorists in some countries and older adults are at a disadvantage in responding to novel, unexpected stimuli (Staplin et al., 2001; Davidse, 2000). This may even lead to older drivers avoiding roundabouts. Simms (1992) reports avoidance of roundabouts by drivers over 70 years old (even in the United Kingdom); although it is unclear whether the roundabouts that were reported as being avoided were only multi-lane or also single-lane. Mesken (2002) made a distinction between single-lane and multi-lane roundabouts when asking older adults to indicate what they regarded as difficult traffic situations: whereas 22% of the drivers mentioned multi-lane roundabouts, only 3% mentioned single-lane roundabouts. So older drivers seem to prefer single-lane roundabouts.

In general, right-angle connections are more effective in reducing driving speed and provide a better view of roundabout traffic for drivers that are about to enter the roundabout, than tangential connections (Brouwer, Herland & Van der Horst, 2000). Bearing in mind the additional problems of restricted head and neck mobility of many older drivers, it is recommended that right-angle connections to the roundabout are used. Another design element of roundabouts that is related to the traffic view is the distance between the roundabout and cyclist and/or pedestrian crossings. A driver leaving the roundabout needs to have a good view of crossing cyclists and pedestrians who have right-of-way and thus should be at a right angle with the cyclist/pedestrian crossing. This angle can only be obtained when the crossing is placed at approximately one length of a car from the circulation area (Linderholm, 1996, cited in Brouwer, Herland & Van der Horst; CROW, 1998, 2002).

5.1.2 Road signs and markings

As people age, visual functions decline and people have more difficulty in dividing attention between, for example, different aspects of the road scene. This makes it more difficult to detect traffic signs and obstacles, and hence to understand the traffic situation at hand. Road design elements can anticipate these difficulties by providing appropriate placement and legibility of traffic signs (e.g. street name signs), conspicuousness of obstacles (e.g. kerbs, medians and traffic islands) and recognizable intersection control (who has right-of-way) and lane assignment.

Street name signing

The legibility of street name signs is important to minimise the time and effort needed to read the street name. One can imagine the kind of danger that could result from a driver who is distracted from the basic driving task for a longer period of time or from a driver who suddenly brakes on approaching a street name sign (Taoka, 1991; Malfetti & Winter, 1987). The main factors that influence the legibility of street name signs are: contrast, luminance, font, letter height, letter width and interletter and interword spacing. These factors increase in importance as a road user's eyesight deteriorates. Older drivers, given their age-related deterioration of visual functions, need more contrast, a higher level of background luminance and larger letter sizes than younger drivers to achieve the same level of comprehension. This can be accomplished by raising the requirements for letter size and the retro-reflectivity of street name signs. The 'Older Driver Highway Design Handbook' recommends a minimum letter-height of 150 mm for use on post-mounted street name signs on all roads where the speed limit exceeds 40 km/h.

Since older adult drivers need more time to act (e.g. turning into a street) after having received directional information (e.g. a street name), the placement of street name signs is also important. Older drivers need sufficient time to prepare and execute their actions and good visibility and prior notification can provide the driver with some extra time to act. Accordingly, street name signs post-mounted along the side of the road and advance street name signs which improve the visibility of street name signs on major roads and grade-separated junctions are helpful. Furthermore, the use of retro-reflective sheeting to provide increased sign conspicuity and legibility is recommended. When different street names are used for different directions of travel on a crossroad, the names on intersection street name signs should be separated and accompanied by directional arrows.

Lane-use control signs

The increased perception-reaction time of older adult drivers (which is responsible for the extra time that older drivers need to act) requires timely warnings of changes in lane configuration. Arrow pavement markings that can provide this kind of information have the disadvantage of being liable to wear, being less visible in bad weather conditions and can be covered by cars at the intersection. The use of overhead lane-use control signs in advance of the intersection as a supplement to pavement markings is therefore recommended. Drivers need to be able to read these signs at least 5 seconds in advance of the intersection (at operating speed; 50 meters at 36 km/h), regardless of the specific lighting, channelisation or delineation treatments implemented at the intersection (Staplin, Lococo & Byington, 1998).

“One-way”and “Yield” signs

Older drivers need to be be informed about the obligatory direction of travel and right-of-way as early as possible. Research in the United States and The Netherlands has shown that older adult drivers are over-represented in wrong-way movements (Crowley & Seguin, 1986; Blokpoel & De Niet, 2000). This over-representation can be explained by older drivers' reduced peripheral vision and their decreased selective attention (the ability to ignore irrelevant information and to discriminate between relevant and irrelevant information). To compensate for these deficits, the most relevant information needs to be signalled in a direct manner to ensure that it receives a high priority for processing in situations where there is a great deal of complexity. This can be accomplished by more conspicuous signs, realized through provision of multiple or advance signs, as well as by placing signs in the driver's field of vision and using signs that are larger in size and have a higher level of retroreflectivity. To prevent wrong-way driving these recommendations are particularly relevant for signs indicating one-way roads and ‘no entry’. However, the same recommendations apply to traffic signs indicating stop-and yield-controlled intersections, since crashes resulting from failure to yield are also over-represented among crashes involving at-fault drivers of the age of 75 and older (Aizenberg & McKenzie, 1997; Zhang, 1988; Davidse, 2000). Moreover, Council and Zegeer (1992; cited in Staplin, Lococo & Byington, 1998) found that both drivers aged 65-74 years old and drivers aged 75 years and older more frequently failed to yield and more often disregarded the stop-sign than a comparison group did (30-50 years old).

Road markings and delineation of raised channelisation

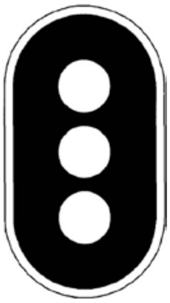
Road markings help the driver to maintain the correct lane position and provide a preview of the course of the road ahead. Given their decreased contrast sensitivity (and their extended perception-reaction time) older drivers need a higher contrast between pavement markings and carriageway to be able to see the markings and to have enough time to act upon them. The same applies to the delineation of discontinuities, such as curbs of traffic islands and medians. Older adults report difficulties in seeing these, resulting in a possibility of running over them (Staplin, Lococo & Sim, 1990; Benekohal et al.,1992; Staplin et al., 1997). Studies in the United States have indicated that driver performance in general – measured by the probability of exceeding lane limits – was optimized when the perceived brightness contrast between pavement markings and the carriageway was 2.0 (Blackwell & Taylor, 1969; Allen, O'Hanlon & McRuer, 1977). This indicates that pavement markings need to be at least three times as bright as the carriageway. However, these studies were not specifically focused on older drivers. Another study compared the performance of the top 5 percent of 25-year-olds (the best performing younger drivers) with the bottom 5 percent of 75-year-olds (the worst performing older drivers). Taking the contrast requirements for the latter group into account, Staplin, Lococo and Byington (1998) recommend a minimum in-service contrast level of 3.0 between the painted edge of the carriageway and the road surface for intersections without overhead lighting. For intersections with overhead lighting a minimum in-service contrast level of 2.0 is deemed to be sufficient.

5.1.3 Traffic lights and fixed lighting

The visual limitations of older adults also need to be taken into account in the design of traffic signals and fixed lighting. Here, the older driver's need for increased levels of luminance and contrast should be weighed against their sensitivity to glare.

Traffic signals

Backplates can provide more contrast between the traffic light and its direct surroundings without increasing the risk of glare and are a good alternative to increased intensity of light. Guidelines recommend that backplates (see picture) should only be omitted where the plate would be too close to the carriageway (CROW, 1996; Regeling Verkeerslichten, 1997). Glare can be further reduced by reducing the intensity of traffic signals during darkness, except when this is unnecessary or undesirable because of the (fixed) lighting of the surroundings (Regeling Verkeerslichten, 1997).



Backplate for a traffic light

Fixed lighting

Lighting is more important for older adults than for the average road user. Both reduced pupil size and yellowing of the lens of the older adult reduce the amount of light reaching the retina. A consequence of this reduced retinal illumination is that sources must be of higher intensity to be seen at night (Olson, 1993). Furthermore, timely warnings of unexpected situations and changes in lane configuration and lane width are helpful to older adults given their increased perception-reaction time and can be achieved by lighting these areas. Wherever feasible, fixed lighting installations are recommended (a) where the potential for wrong-way movements is indicated through crash experience or engineering judgement; (b) where twilight or night-time pedestrian volumes are high; and (c) where shifting lane alignment, turn-only lane assignment, or a pavement-width transition forces a path-following adjustment at or near the intersection (Staplin et al., 2001).

5.1.4 Exits and entries of motorways

Both intersections at-grade and grade-separated interchanges pose problems for older adult drivers. A study by Staplin and Lyles (1991) showed that drivers over 75 are over-represented as the driver at fault in merging and weaving crashes near interchange ramps. Age differences in interchange crashes and violations may be understood in terms of driving task demands and age-related diminished driver capabilities (Staplin, Lococo & Byington, 1998). Merging and weaving on interchanges involves the processing of a large amount of information in a short period of time and at high speeds, while maintaining or modifying position within the traffic stream. Under these circumstances, several functional limitations of older adult drivers come into play including a slower processing of information, reduced visual acuity and peripheral vision, and reduced flexibility of head and neck. When merging and weaving take place in the dark or under bad lighting conditions, poor night vision and increased sensitivity to glare are also involved.

During focus group discussions that were held as part of a study by Lerner and Ratté (1991), older adult drivers indicated that interchanges could be improved by eliminating weaving sections and short merge areas; and improving exit signing by better graphics and more information on upcoming exits.

Specific measures that apply to these and other road design elements of interchanges relate to:

- exit signing;
- design of acceleration and deceleration lanes;
- fixed lighting at interchanges; and
- prevention of wrong-way manoeuvres.

Exit signing

The usefulness of directional information is determined by its legibility and the time available to act upon the information. Older adult drivers, given their age-related deterioration of visual functions, need more contrast, a higher level of background luminance and larger letter sizes than younger drivers to achieve the same level of comprehension. This can be accomplished by raising the requirements for letter size and retroreflectivity of direction signs. Research has shown that the US standard for the height of capital letters (the “legibility index” of 50 ft/inch (6.2 metre per 10 mm letter height); also used in e.g. the Netherlands) is insufficient for the visual ability of 30 to 40% of drivers who are 65-74 years old, even under favourable contrast conditions (Transportation Research Board, 1988). Based on research by Olson & Bernstein (1979) and Olson, Sivak & Egan (1983) the ‘Older Driver Highway Design Handbook’ recommends the raising of the legibility standard to one that assumes that a 10-mm tall letter is legible at 4 metres. The time available to act on directional information can be prolonged by multiple use of advance signing on exits and on lane configuration. This is particularly important for older drivers who have an increased perception-reaction time.

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Design elements for acceleration and deceleration lanes

Merging poses high demands on several visual, information processing, and physical abilities; abilities that decline with age. In addition, the act of merging has to be performed under pressure of time, since the end of the acceleration lane restricts the possibility to merge. Older drivers' difficulties in merging, at worst resulting in a crash, illustrate the extra time needed to merge. Therefore, a vital measure for improving the safety of merging by older drivers is the length of the acceleration lane. In a survey of drivers aged 65 and older, 49% of reported that the length of motorway entry lanes was a highway feature that was more important to them now than 10 years previously (Benekohal et al.,1992; Staplin, Lococo & Byington, 1998). No research is available on the minimal length of acceleration lanes necessary to accommodate older drivers, and general guidelines on acceleration lane lengths differ between countries. For example, the Dutch guidelines prescribe longer lane lengths (350 m) than those recommended in the 'Older Driver Highway Design Handbook' (based on US guidelines; AASHTO (1984). However, the longer the acceleration lane, the better. In addition, a parallel design should be used for entrance ramps to enable the driver to obtain full view of following traffic (instead of a taper design, which does not have a separate acceleration lane and leads the driver directly onto the traffic lane; Staplin, Lococo & Byington, 1998).

As far as deceleration lanes are concerned, good sight is needed of the following curve. The acquired information gives the driver the opportunity to assess the required vehicle control actions (braking, steering). The visibility of the curve can be improved by post-mounted delineators and chevrons (Staplin, Lococo & Byington, 1998).

Fixed lighting at interchanges

Lighting is more important for older adults than for the average road user (see Section 5.1.3 on Fixed lighting). On motorways fixed lighting should be implemented at exits and entries. The 'Older Driver Highway Design Handbook' recommends complete interchange lighting, but where this is not feasible, a partial interchange lighting system comprised of two high-mast installations per ramp is recommended, with one fixture located on the inner ramp curve near the gore, and one fixture located on the outer curve of the ramp, midway through the controlling curvature (Staplin, Lococo & Byington, 1998). In the case of a partial interchange lighting system, Dutch design guidelines recommend additionally illuminating a part of the carriageway (AVV, 1993).

For evidence on the need of motorway lighting by older drivers, Staplin et al. (2001) refer to the results of a survey by Knoblauch, Nitzburg and Seifert (1997): 70% of the older drivers in the ages of 50 to 97 indicated that more lighting is needed on motorways, especially on interchanges, construction zones and toll plazas.

Design elements to prevent wrong-way manoeuvres

The most important cause of wrong-way driving among older drivers is using the exit as an entry. Measures to address this problem mainly focus on making the entry more conspicuous. Compliance with the existing specifications for the signing and visibility of entries, and maintenance of markings are amongst the most important measures to be taken to prevent wrong-way driving. The siting of warning signs is also important. For example, the "Do not enter/go back" signs used in the Netherlands to warn drivers against entering an exit (see picture), which are located in the median between the exit and entry on half cloverleaf junctions, are often also visible when driving into the entry. As a result, drivers are used to seeing them and learn to ignore them which can reduce the effectiveness of signs and even lead to their having an adverse effect. For this reason, it is recommended that the signs should be placed or shielded in such a way that they cannot be seen and do not appear to be intended for traffic on the entry.

Wrong-way arrow pavement markings near the terminus on all exit ramps, accompanied by red raised-pavement markers facing wrong-way traffic are also recommended. Where adjacent entrance and exit ramps intersect with a crossroad, the use of a median separator is recommended, with the nose of the separator delineated with reflecting paint and extending as close to the crossroad as is practical without obstructing the turning path of vehicles. In addition, it is recommended that the 'obligatory direction of travel' sign is posted on the median separator nose (De Niet & Blokpoel, 2000; Staplin, Lococo & Byington, 1998).

Incidence of wrong-way driving

Crashes following wrong-way driving account for only a very small part (± 1%) of the total number of crashes on motorways. This applies to all age-groups, but with considerable differences between the age-groups. Dutch figures show that the percentage of wrong-way drivers among drivers involved in a crash increases above the age of 55, with drivers of 70 years and older having the highest percentage (0.65% compared to an average of 0.06%). Looking at the wrong-way manoeuvres that led to a fatality or a serious injury, one third of the wrong-way drivers was aged 70 years or older (Blokpoel & De Niet, 2000). Staplin et al. (2001) report similar findings in studies by Tamburri & Theobald (1965) and Lew (1971): both studies showed that drivers above the age of 70 experienced the most wrong-way incidents and crashes.

An analysis of the official police reports of crashes in the Netherlands that were caused by wrong-way drivers showed that about half of the wrong-way manoeuvres that led to a crash, started on the exit road (De Niet & Blokpoel, 2000). These wrong-way manoeuvres occurred predominantly during darkness and involved older drivers (age 55 and older). Drivers wanted to enter the entry road to the motorway correctly but turned left onto the exit road too soon. De Niet & Blokpoel (2000) also did some supplementary research to find out to what degree road design could have played a role in wrong-way driving. To this end, they visited locations where drivers started wrong-way manoeuvres. It turned out that these locations could have encouraged turning off prematurely by (1) a conspicuous exit and poor view of the entry, leading the driver to the exit road; (2) worn-out markings and misplaced or missing signs making it difficult to know what is permitted; and/or (3) a curve of the subordinate road onto the exit that is not tight enough to hinder a premature turn-off.

The combination of the earlier mentioned age-related functional limitations of the older adult and several characteristics of the above-mentioned locations make older adults more vulnerable to difficulties when entering the motorway. For example, older drivers need a higher contrast between pavement markings and carriageway to be able to see the markings and still have enough time to act upon them. Furthermore, the decreased ability to discriminate between relevant and irrelevant information and to ignore irrelevant information raise the importance of making the entry more conspicuous than the exit. This not only explains the overrepresentation of older adult drivers among wrong-way drivers, but it also shows that measures to prevent wrong-way driving are particularly important for the safety of older adult drivers.

See also ERSO web text on Roads

5.2 Advanced Driver Assistance Systems (ADAS)

Advanced Driver Assistance Systems (ADAS) provide personal assistance in a road environment that does not always take into account the possibilities and limitations of the older driver. An analysis of the strengths and weaknesses of the older driver has shown that the most important need for support stems from the difficulties that older drivers have to (Davidse, 2007):

- judge whether fellow road users are approaching the same intersection and at what speed;
- notice other road users while merging and changing lanes;
- notice traffic signs and signals;
- react quickly in a complex traffic situation.

These difficulties stem from functional limitations such as a decrease in motion perception, peripheral vision, flexibility of head and neck, selective attention, and speed of processing information and decision making. ADAS can compensate for these limitations and contribute to a reduction of the crash involvement of older drivers if they have one or more of the following functionalities (Davidse, 2006, 2007).

- draw attention to approaching traffic;
- signal road users located in the driver's blind spot;
- assist the driver in directing his attention to relevant information; and/or
- provide prior knowledge on the next traffic situation.

Examples of ADAS systems which have these functionalities are collision warning systems aimed at intersections and in-vehicle signing systems (see Section 5.2.1). ADAS can also improve the mobility of the older driver, or reduce injury severity. Examples of those systems are vision enhancement systems, navigation systems and mayday systems(see Section 5.2.2).

Using ADAS to improve the safety or mobility of the driver involves more than making sure that the supported sub-task is carried out safely. It also requires that the support provided does not have any negative effects on the other elements of the driving task. Examples of negative side effects are increased task load due to a bad design of the human machine interface, and the effects of behavioural adaptation(see Section 5.2.4).

5.2.1 ADAS for crash avoidance

Several studies have mentioned the potential for ADAS to provide tailored assistance for older drivers (Mitchell & Suen,1997; Shaheen & Niemeier, 2001; Färber, 2000). ADAS have potential to compensate for limitations in motion perception, peripheral vision, selective attention and decreased speed of processing information and decision-making (Mitchell & Suen,1997). The ADAS with the most potential for crash avoidance are summarized in Table 5 below.

Table 5: Desired functionalities for older drivers and ADAS that appear to offer them

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

Source: Davidse, 2007, adapted from Mitchell and Suen (1997)

Many of these systems are still being developed and little research has been done on the effects on driver behaviour. If research on the effects on driver behaviour has been carried out, drivers involved were generally young. As a result, little can be said on whether these systems - when available - will actually be used by older drivers and will produce road safety benefits (Davidse, 2006, 2007). Fortunately, in the past five years the development of ADAS for older drivers receives growing attention from both car industry and research (see for example Davidse et al., 2009; Pereira, Bruyas & Simoes, 2010; Gelau, Sirek & Dahmen-Zimmer, 2011).

5.2.2 ADAS for enhanced mobility and lower injury severity

Systems that could enhance the mobility of older drivers, or that could lower their injury severity, are:

- night-vision enhancement systems,
- navigation systems, and
- mayday systems.

These systems seem to be helpful for drivers who have difficulties driving in the dark or driving in an unfamiliar area, and for those who have subjective feelings of insecurity respectively (Mitchell & Suen, 1997; Fildes & Charlton, 2005). Hence, these systems are particularly suitable to enhance the mobility of older people.

Mayday systems can also reduce the time to medical treatment, thereby reducing injury severity. Usage of the other two systems may also lead to a reduction of the crash rate of older drivers by compensating for impaired night-time visual acuity and by preventing search behavior respectively. Whether this reduction in crash rate will also lead to a reduction in the number of victims is dependent on the magnitude of the reduction in crash rate. The latter reduction should be larger than the increase in mobility due to system usage (see also Section 5.2.4 on Behavioural adaptation).

5.2.3 User acceptance

Several studies have shown that older drivers are to a large extent willing to consider using and buying ADAS that meet an existing need, such as reversing aids, and collision warning systems that are aimed at the prevention of crashes on intersections (Oxley & Mitchell, 1995; Viborg, 1999). Furthermore, older drivers are also willing to accept systems that (partly) take over vehicle control (like automatic speed or distance adjustment) or that give feedback messages (Viborg, 1999). These results indicate that older drivers will also accept ADAS as a means to improve their safety. 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.

5.2.4 Pre-conditions for safe use of ADAS by older drivers

Knowing which types of ADAS have the most potential to improve the safety of older drivers is not enough to actually improve their safety. Besides the fact that the user will have to accept, buy, use and trust the system, the driver should also be able to understand the information the ADAS sends to him (via a display or by 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. The support provided by the system(s) should not have any negative safety consequences. These preconditions can be met by:

- complying with the guidelines for human machine interfaces,
- making sure that ADAS work together, and
- being aware of the effects of behavioural adaptation.

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 (Oxley, 1996). There are several reports available which describe the current guidelines (see Green, 2001a for an overview). Caird, Chugh, Wilcox and Dewar (1998) have summarized these guidelines and in addition included a section on guidelines for older drivers. The design guidelines for older drivers are summarized in Table 6, along with the functional limitations of older adults which they take into account.

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Table 6: Functional limitations and relevant design principles

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

Source: Davidse, 2007; based on Caird et al. (1998) and Gardner-Bonneau & Gosbee (1997)

Whereas the guidelines in this table have all been selected based on the older adult's functional limitations, it should be kept in mind that designers can 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 adults (Gardner-Bonneau & Gosbee, 1997).

Older drivers should not only be kept in mind during the design phase, but also afterwards. ADAS should be evaluated using both younger and older drivers. The latter experience considerably more difficulty in completing telematic 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 do so as well.

ADAS should work together

When car owners install or manufacturers equip more than one ADAS in a vehicle, the presence of several displays may introduce new problems. Each display will attract the attention of the driver. Older drivers will suffer the most since age differences become more evident as tasks are becoming more complex. This will result in longer reaction times (see for example McDowd & Craik, 1988). Messages sent simultaneously from different ADAS will increase the pressure on the driver even further. In effect, the presence of several, independently functioning systems increases the task load which is the opposite aim of ADAS in lowering the task load.
Co-ordination between the installed ADAS may overcome these difficulties (ETSC, 1999). In addition, it can also prevent systems from sending conflicting instructions or, even worse, carrying out conflicting actions. The coordination between systems can be implemented in several ways. Heijer et al. (2001) suggested that one ADAS should be able to support the driver in a set of problematic situations instead of separate ADAS each supporting 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 (Vonk, Van Arem & Hoedemaeker, 2002; Färber & Färber, 2003; Piechulla, 2003; Wheatley & Hurwitz, 2001).

Behavioural adaptation

The phenomenon of behavioural adaptation implies that people in many cases adapt behaviour to some of the improvements of a system by taking more chances (see Dragutinovic, Brookhuis, Hagenzieker & 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 as risk compensation and risk homeostasis (Wilde 1982). A form of behavioural adaptation that could arise among older drivers, is the withdrawal of compensatory 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 (Hakamies-Blomqvist, 1994a; Aizenberg & McKenzie, 1997; Zhang et al.,1998; McGwin & Brown, 1999). When the large-scale introduction of night vision enhancement systems makes older adults drive at night again, this will increase their mobility and improve their quality of life. However, it remains to be seen whether the use of night vision enhancement systems will provide similar risk compensation for impaired night-time visual acuity to the older driver's compensation strategy of not driving at night (Caird et al., 1998; Smiley, 2000).

See also ERSO web text on eSafety

5.3 Vehicle design and vehicle safety

Measures which relate to the vehicle are aimed at improving the physical access to the car, at making it easier to operate the vehicle, or at improving the safety of the occupants. The first two types of measure primarily relate to vehicle design, the latter to vehicle safety.

5.3.1 Vehicle design

Age-related muscular-skeletal impairments such as osteoarthritis, rheumatoid arthritis and decreasing strength may all affect the range of motion of limbs, making it more difficult to enter and exit vehicles and to reach driving controls or handle the steering wheel. To facilitate older people's entry and exit of a car, door frame height, width of door opening, doorsill height and seat height should have the right dimensions (see Table 7).

Table 7: Recommended car access dimensions

Car part	*Recommended dimension (cm)*
Door frame height above ground	133-138
Width of door opening	80-100
Seat height above ground	50-60, 50 optimum
Doorsill height	36-40
Doorsill to car floor	4-9, 6 optimum
Seat front edge	35-45
Door opening angle	70 , 90 when assistance needed

Source: Institute of Consumer Ergonomics, 1985; Petzäll, 1991, cited in OECD, 2001

In addition, handles on the doorframe can help during entry and exit of the car. Equipment that can make it easier to operate the vehicle are power steering, automatic transmission, and wide-angle and planar rear-view mirrors to support drivers suffering from impaired field of vision or restricted head movements (OECD, 2001). Finally, Advanced Driver Assistance Systems (ADAS) such as in-vehicle signing systems and night-vision enhancement systems can also compensate for functional limitations (see Section 5.2).

5.3.2 Vehicle safety

Older adults are more vulnerable than younger adults: their injuries will be more severe given an identical collision impact. Given the estimated increase in the number of older drivers into the future, improved crashworthiness of vehicles is very important. However, currently, crash-test dummies and models are based on averagely fit people. Test dummies capable of modelling the effects on an older occupant are needed to be able to take into account older occupants' frailty when testing and improving vehicle safety (OECD, 2001).

In addition, occupant protection can be enhanced by the further development of seat belts and airbags, particularly through force-limiting features. In their current state of development, seat belts are beneficial to older occupants. However, in some circumstances, they may also contribute to the incidence of injuries. Recent developments suggest that this drawback is well on its way to being resolved, by the use of a 'force limiting feature', which controls the maximum restraining force exerted by the shoulder belt. Other technological advances that are likely to be especially relevant for the protection of older occupants include (Pike, 1989; cited in OECD, 2001):

- Intelligent restraint systems, capable of adjusting for lighter, older occupants;
- Dual-stage airbags to minimise aggressive airbag contacts in moderate crashes;
- Active head restraints to minimise soft tissue injury and whiplash injuries to the neck;
- Side airbags to protect the head and chest in side collisions, such as crashes when turning left in which older drivers are overrepresented.

See also ERSO web texts on Vehicle Safety and eSafety

5.4 Education/training

Formal education and training are important ways to inform older drivers of the physical and cognitive changes experienced as part of the ageing process, on the implications of ceasing to drive and on the choice of safer vehicles. In addition, other people with a particular interest in the safety and mobility of older people, such as doctors, family, vehicle manufacturers, highway engineers, but also other drivers who share the road with older drivers should be informed of the difficulties experienced by older drivers in traffic. The latter could even involve this topic being included in the curriculum for obtaining a driver's licence. The next two sections focus on educational programmes and training programmes for the older driver:

5.4.1 Informing the older driver

Older drivers need information on the physical and cognitive changes that accompany age-ing, and on the implications of ceasing to drive. In particular, it is important to inform older drivers of:

- The potential for declining sensory and cognitive abilities, difficulties that may arise in traffic as a result of these declining abilities, and how to modify driving strategies to avoid these difficulties. Recognition by the individual driver is the essential first step in effective remedial action. At the same time, information must be available to provide reassurance that with care and planning, drivers can continue to drive safely well into old age.
- Vehicle equipment and ADAS which are available to make driving easier.

- Increased vulnerability, and the importance of using protection devices.
- Influence of age-related illnesses and prescribed medication on driving abilities.
- Information about the procedure to be followed to extend the driving licence.
- Possible decision to no longer drive a car: making this debatable, and discussing the roles that relatives and family doctor can play.
- How and where to seek and access mobility alternatives to the car.

(Maycock, 1997; OECD, 2001).

The above information can be disseminated in special meetings organized by traffic safety organizations or by senior citizens' leagues, or it can be published in leaflets to be distributed in buildings frequented by older people. One specific occasion for distributing leaflets would be the medical examination that is required in many European countries to renew the driving licence. Examples of leaflets are:

- Drive on! Advice for older drivers, a leaflet by the Department for Transport of the UK.
- Seniors in traffic, a brochure in Dutch and French by the Belgian Institute for Road Safety.
- Driving for all ages, a brochure by the Finnish National Transport Authority.

A useful discussion on how the public and private sectors can influence older drivers' self-regulation was published by the British Royal Automobile Club Foundation (Berry, 2011).

5.4.2 Training the older driver

Training programmes provide a good opportunity for informing the older driver of the physical and cognitive changes that accompany ageing, difficulties that may arise in traffic as a result of these changes, and how to modify driving strategies to avoid these difficulties. In addition, attention can be paid to difficult traffic situations in the neighbourhood and new traffic rules. The programme can be supplemented with a practical training module or assessment drive. Examples of training programmes are the German programme called 'Ältere aktive Kraftfahrer' and the BROEM-drives that are organised in the Netherlands (see Box).

Examples of training programmes

The German programme 'Ältere aktive Kraftfahrer' consists of four successive seminars that are run in the style of a workshop. Participants are encouraged to examine their own behaviour and driving habits behind the wheel, by discussion and the sharing of experiences. The courses offer older drivers the opportunity of keeping up to date with the latest driving regulations and of resolving individual problems which may have arisen from their own driving experiences.

The Dutch BROEM is a voluntary assessment drive for drivers over 50 years of age; it is not a driving test. The BROEM drive includes assessment of driving style, eyesight and response times, and provides a refresher course on traffic rules. The drive is supplemented by a reference book which includes information on the effects of age on driving and gives helpful advice to older drivers. After the drive, the participant is given a report indicating his strengths and weaknesses, with suggestions for improvement.

5.5 Assessing fitness to drive

The assessment of an older person's fitness to drive can take place both as part of renewal of the driving licence at a specified age and when a health problem has been identified.

5.5.1 Licensing procedures for older drivers

Practice in European countries on the licensing of older drivers varies. Some countries require renewal of the driving licence at a certain age, whereas others do not. Those countries that do, often require some sort of medical examination (See Box on licensing procedures). Increasingly, researchers recognise that age-based mandatory assessment programmes targeting older drivers are unlikely to produce safety benefits and may have counter-productive results. One of the few evaluations of existing driver testing programmes compared Finnish and Swedish licensing practices (Hakamies-Blomqvist et al.,1996). Finland requires regular medical check-ups in conjunction with licence renewal starting at age 70, whereas Sweden has no such age-related control. A comparison of Finland and Sweden shows no apparent reduction in crashes as a result of the Finnish programme. However, Finland had a higher rate of fatalities among unprotected older road users than Sweden, arguably the result of an increase in the number of older pedestrians who had lost their driving licence. An Australian study reached a similar conclusion. Although the state of Victoria has no age-related licensing controls, its crash statistics for older drivers are no worse than those of other states with established testing programmes (Torpey, 1986).

Given the variation in older-driver licensing programmes in European countries, it is understandable that evidence relating to the effectiveness of age-related controls is inconclusive. However, one outcome is clear: many drivers (especially women) voluntarily stop driving rather than undergo a medical examination or a driving test (Levy, 1995; Hakamies-Blomqvist & Wahlstrom, 1998). Some give up their licences for health reasons or owing to difficulties in driving, although it remains to be established whether these factors are severe enough to warrant cessation of driving (OECD, 2001).

Licensing procedures in selected European countries

Practice in European countries governing the licensing of older drivers varies The results of an OECD survey show some of the differences in medical requirements for licence renewal. In addition to the medical requirements for renewal of the driving licence, some countries also require older drivers to pass driving tests.

Country	*Renewal procedure*	*Renewal interval*	*Medical requirements for renewal*
Belgium	No	No renewal required	None
Denmark	Yes	At age 70, issued for four years At age 71, issued for three years At ages 72-79, issued for two years At ages 80+, issued for one year If ill, shorter terms possible.	Doctor's certificate required
United Kingdom	Yes	From age 70, mandatory renewal for three-year periods	Self-declaration of ability to meet vision standard required. Any medical condition that could affect driving must be reported to the Licensing Agency
Finland	Yes	At age 45, renewal every five years As of age 70, renewal period depends on the physician.	After age 45, medical review every five years, covering general health status and vision. Renewal requires medical examination and verification of ability by two people.
France	No	No renewal required	None

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Germany	No	Renewal not determined by age	None
Ireland	Yes	Annual renewal regardless of age	At 70, a certificate of medical fitness is required
Italy	Yes	Ten-year renewal up to age 50 Five-year renewal after age 50 Three-year renewal at age 70.	Medical test required with renewal
Netherlands	Yes	At age 70, medical review required every five years	Depending on physical condition, medical review may be more frequent, vision test required
Portugal	Yes	At age 70, renewed every two years	At age 70, a medical exam is required every two years
Sweden	No	No renewal required	None

Source: OECD, 2001

5.5.2 Consultation of doctors

When a health problem has been identified, the question of whether to continue driving depends not on a medical diagnosis, but on the functional consequences of the illness. Moreover, a given condition may affect an individual's fitness to drive in different ways and to varying degrees (OECD, 2001; Holland, Handley & Feetam, 2003).

Although medical assessment seldom provides sufficient grounds for an absolute assessment of driving ability, it does play a role when there are genuine reasons to question older drivers' functional capabilities. Physicians, especially those working in primary care, represent an important first contact and information source and are in a position to make judgements and give advice to the patient about fitness to drive. In addition to assessing specific conditions and disabilities, physicians also need to advise on the effects of any prescribed drugs on driving (OECD, 2001).

6 Safety versus mobility and quality of life

A licensing procedure that results in people losing their driving licence when they can still drive a car safely is undesirable for a variety of reasons. Firstly, the fatality rate for older cyclists and pedestrians is many times greater than for older drivers. Consequently, they are safer in a car. In addition, older people will often have already stopped cycling, partly because of loss of balance. Saying farewell to their car often is also a farewell to part of their social lives. This can have negative consequences for the well-being of the individual, but also for society as a whole (e.g. the extra costs of door-to-door community transport). At the same time older people who still drive do not pose a disproportional danger to other road users. They are more often severely injured themselves (killed or hospitalized) in a collision with a younger motorist than that they, as a motorist, cause severe injury to a younger road user (OECD, 2001; SWOV, 2012).

When safe mobility as a car driver is indeed no longer possible, alternative means of transport should be made available to ensure the mobility of older people. Many countries do this. Examples of alternative means of transport are: conventional public transport services, bus service routes, taxis, and dial-a-ride service for door-to-door travel. No single form of transport provides mobility for all people under all circumstances. A family of services is needed that enables travellers to select the one that best suits their requirements for a particular journey.

6.1 The importance of the private car

Driving a car is important for people in general because it provides status and the opportunity for personal control and independence (Ellaway et al., 2003; Steg, 2003). In sparsely populated areas, owning a car is even more important, since it provides the only opportunity for travelling long distances due to a lack of public transport. For older people, having more difficulties walking (to the bus stop) and cycling, driving is often the only option for independent mobility. Several studies have found that over 90% of older drivers indicate that giving up driving would restrict their independence and mobility (Rabbitt, Carmichael, Jones & Holland, 1996; Jansen et al., 2001). The same drivers expressed anxiety about the poor quality of public transport services. This anxiety seemed to be based on reality because 50% of those respondents who already had given up driving felt public transport to be, at least in some measure, inadequate (Rabbitt, Carmichael, Jones & Holland, 1996).

Before older people stop driving, they usually reduce how much they drive and limit their driving to local journeys in familiar areas and under easy driving conditions. The better the provision of alternative means of mobility, the more likely a driver is to start using them for journeys, long before ceasing to drive. This makes it easier to remain mobile after ceasing to drive. The lack of attractive and feasible transport alternatives to the private automobile, coupled with land-use patterns that make walking difficult or impossible, contributes to the problems experienced by people who have to stop driving, notably in North America. However, similar problems occur in Europe for older people living in suburbs and rural locations, as they increasingly do. In Great Britain, older drivers appear to be more likely to stop driving if they live in urban areas where walking, buses and taxis offer realistic mobility alternatives (OECD, 2001). The ability to go everywhere and do everything without a car is also mentioned in surveys on reasons for driving less. However, the most important factors for ceasing to drive seem to be safety, health, and finance (Rabbitt, Carmichael, Jones & Holland, 1996; Jansen et al., 2001). Men more often give up driving because of bad health. Women tend to retire from the wheel earlier and for less pressing reasons, such as driving seldom (Hakamies-Blomqvist & Wahlstrom, 1998; Hakamies, Sirén & Davidse, 2003; Jansen et al., 2001).

6.2 The effects of giving up driving

Stopping driving is likely to reduce mobility and negatively affect the quality of life. The consequences have been described to be mostly negative (for an overview see Harrisson & Ragland, 2003; Hakamies, Sirén & Davidse, 2003). Stopping driving has been found to reduce the number of out-of-home activities (Marottoli et al., 2000) and to be related to increased depression (Fonda, Wallace & Herzog, 2001). It has also been argued that giving up driving has a negative impact on an older person's identity, his feeling of independence, and his dignity (Bonnel, 1999; Burkhardt, Berger & McGavock, 1996; Carp, 1988; Eisenhandler, 1990; Peel, Westermoreland & Steinberg, 2002). These negative feelings are related to having to give up something that has been a large part of their adult life and was closely identified with their perceived roles in family and society. Having ceased driving, most people dislike asking for rides. To keep their dignity, people often insist that they provide some reciprocal service (cooking a meal, babysitting) or gift in return for the ride (Burkhardt, 1999; Carp, 1988).

6.3 Alternative means of transport

The availability of means of transport other than the car is one of the most important ways to maintain older people's mobility. Such options allow older people to travel. Viable transport options need to provide opportunities for spontaneous travel and flexibility in modal choice in order to enable older users to reach the desired destinations. Such options need to ensure that the entire travel chain is suitable for older people, taking account of older people's capabilities and limitations and be affordable and accessible (OECD, 2001).

Alternatives to the car are often provided by community transport and para-transit (Dial-a-Ride) services. These can be useful, although a drawback of these services is that they often require advance booking. They rarely permit spontaneous travel of the kind that is possible by car or on foot. Powered wheelchairs, scooters and golf carts constitute another class of mobility alternative that does not require a driving licence. These vehicles allow for spontaneous travel and are being used for journeys of up to about 4 km which are made under favourable weather conditions (OECD, 2001). No single form of transport provides mobility for all people under all circumstances. A family of services is needed that enables travellers to select the one that best suits their requirements for a particular journey. These services include:

- Conventional public transport services, which are accessible to passengers in wheelchairs, wherever possible.
- Bus service routes using small vehicles that pick up and discharge passengers close to origin and destination. This service is particularly appropriate for areas where demand is low (e.g. in rural areas).
- Conventional taxis, often with user-side subsidies in order to reduce the fare
- Dial-a-Ride service for door-to-door travel for passengers who require assistance and/or who use a wheelchair that cannot be accommodated by a taxi or accessible bus

Accessible pedestrian infrastructure to allow access to all transport services and to make journeys wholly on foot or by (powered) wheelchair or scooter.

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European Commission

Project co-financed by the European Commission Directorate General for Mobility & Transport

The Older Driver Highway Design Handbook

The 'Older Driver Highway Design Handbook' by Staplin, Lococo and Byington (1998), and its second edition 'Highway Design Handbook for Older Drivers and Pedestrians' (Staplin, Lococo, Byington & Harkey, 2001) can be regarded as important reference books on the subject of road design elements that take the older adult driver into account. These two handbooks contain recommendations regarding the design of highways including the references on which these recommendations were based. A major advantage of these handbooks is that all recommendations have been presented to engineers with the request to check whether these recommendations would contribute to a solution of existing problems of older adult drivers, and whether they would apply these recommendations to their own roads. Feedback from the engineers has been incorporated in the handbooks.

Since the infrastructure in the United States is rather different than in Europe, it would not be wise just to copy all proposed measures. Therefore, Davidse (2002) thoroughly screened all recommendations with the help of Dutch engineers on the possibility and desirability to translate them to the European situation. In her report, only those recommendations were included that were judged to be suitable for the European situation and that were related to intersections and interchanges. Where possible, these recommendations were complemented with the results of studies that were not included in the reference list of the American handbooks. An English translation of the report is included in Hakamies-Blomqvist et al. (2004).

Project co-financed by the European Commission Directorate General for Mobility & Transport