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VEHICLE LIGHTING AND THE AGING POPULATION

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16. Abstract

Old drivers and old road users in general, have high injury and fatality rates in road traffic. Furthermore, the proportion of old road users and old drivers will increase rapidly during the coming decades. Night travel has proven most difficult for old persons. The purpose of this study was to analyze this situation from the vehicle lighting point of view in order to propose vehicle lighting improvements that could be of special benefit to old road users.

A literature review of current knowledge concerning age, visual performance, and accident involvement was carried out. This was followed by an analysis of the present vehicle lighting problems. Based on the results from these analyses, a number of proposals for improvements were presented. The main proposals concerning illumination systems are as follows: more illumination to increase visibility in spite of higher glare, wider illumination to improve road guidance, a softer cut-off to decrease aiming sensitivity, and keeping headlights clean and correctly aimed. The main proposals concerning signaling and marking lights are the following: two intensity levels (for day and night), small, high-mounted turn signals, and higher light-source reliability. Mandatory daytime running lights are proposed. Interior lighting should be improved in a number of aspects. All of these proposed improvements should be beneficial not only for old drivers, but also for other drivers. Finally, the visibility and safety effects are estimated, research needs are pointed out, and technical and economic problems are discussed.

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Executive Summary

The purpose of this study is to analyze existing literature and general knowledge in order to describe problems with present vehicle lighting systems (illumination, signaling, marking, conspicuity, and interior) related to aging road users, and to propose lighting modifications and measures intended to counterbalance such age-related problems. There are three main reasons for doing this study. One reason is that the number of old persons in road traffic during the next twenty-five years will increase faster than any other road user age group in the developed countries. Another reason is that old road users are found to have high risks in road traffic. The third reason is that nighttime driving is perceived by old persons as very difficult and dangerous.

Initially a review is made of present knowledge concerning problems with old persons in road traffic. It is concluded that mobility is an important variable in present social and professional life. But old persons restrict their traveling substantially because they find it difficult and potentially dangerous. Concerning drivers, this self-restriction typically includes refraining from driving at night, on icy roads, in rush hour, in rain, through intersections, and in reverse.

It is common to distinguish several aspects of aging. One aspect concerns the central nervous functions and is often called cognitive. The main effect of aging on the cognitive functions seems to be difficulties in handling complex and novel situations, especially under time pressure. This leads to divided-attention problems, missed stimuli, distraction, and long decision and reaction times.

Several countermeasures have been proposed to reduce the high accident involvement of old road users. These fall into three general categories: (1) restrict the driving of old persons, (2) inform, educate, and train old persons about their driving capacities and risks, and (3) facilitate mobility for old road users (including drivers). Driving restriction is important for those who do not realize their own limitations, while information, education, and training can be helpful to those drivers and others. Finally, in order to participate in society and to continue to live active lives, old persons need mobility. Therefore the third approach—change the conditions so that the old persons can maintain their mobility—is the best countermeasure whenever it is possible.

Another aspect of aging concerns physiological impairment, primarily of the senses. The impairment of hearing is of secondary importance to drivers, but it is of primary importance to pedestrians and cyclists. Vision is the main sense for moving in road traffic. There are many visual functions that deteriorate with age: decreased pupil size, more distant near point, smaller number of active receptors, decreased eye-movement capacity, reduced capacity to adapt to low light levels, reduced visual acuity, reduced contrast sensitivity, impaired peripheral vision, higher glare sensitivity and longer glare recovery, impaired color vision, and reduced speed and motion perception. Some of these deficiencies are related to changes in more central capacities. Examples of such functions are visual search, divided attention, and useful field of view. None of the relatively simple visual functions shows high correlation with driver accident involvement. However, more complex functions such as divided attention and useful field of view appear to be more predictive of accident involvement.

The performance of present vehicle lighting systems under realistic, real-world conditions is not fully reflected in how they perform when formally tested for compliance with regulations. Especially the illumination systems, but also the signaling systems, are designed for ideal situations and do not perform equally well in the full range of real traffic situations.

To analyze the problems that old persons have with various vehicle lighting systems, and the countermeasures that could be suitable, three approaches were taken using accident data, knowledge about changes in visual performance with age, and finally a formal driver model. The conclusions from these analyses were used to make a number of proposals for modifications of vehicle lighting systems to facilitate visual tasks, especially for old road users.

The main problem in adapting low-beam headlighting systems to the old road user is the balance between increased illumination for better visibility and decreased glare. It is suggested that, despite higher glare sensitivity, the old driver would benefit from more illumination. In order to decrease the sensitivity of headlighting to changing conditions (mainly road geometry) a comparatively soft cut-off is desirable. The headlights should be kept in better condition (with regard to aiming, dirt, haze, scratches, voltage, bulb failure, etc.) than is presently the case. Furthermore, because of the impaired road guidance experienced by old road users, more light along the road sides would be beneficial.

Dual-level signal lights should be introduced in order to compensate for the reduced contrast sensitivity of old persons. Furthermore, the maintenance of the signaling and marking lights should be improved. Turn signals should be made smaller, and should be positioned higher up on the vehicle, to be more in the central field of the other road users. Turn signals should also be separated from the headlights and other rear lights. Some type of contour marking of vehicles should be introduced to facilitate distance estimation, especially for old road users.

Two front daytime running lights (DRLs) should be mandatory to facilitate the detection of other vehicles during daylight. Low beams seem to work fine as DRLs, but are not optimal from a lighting engineering point of view. A wide light distribution is appropriate. No other lights should be on together with the DRLs. The switching should be automatic.

Present interior lighting in cars could be substantially improved. Interior lighting of controls, of handles and locks, of storage compartments, for reading, and for stepping in and out of the car should be improved.

The potential improvements in visibility distances due to improved illumination systems are estimated to be 10 to 20 percent. The safety effect will be smaller—probably a reduction of nighttime accidents by 1 to 2 percent. The proposals for improvement of signaling and marking lights may reduce vehicle collisions by up to 5 percent. DRLs should reduce daylight collisions by about 5 percent. Interior lighting improvements will mainly improve comfort and only indirectly have any effect on safety. The proposed changes should be favorable also for other road user groups—not only for old road users.

Finally, some comments are made concerning basic and applied research needs, and technical and economic problems. None of the proposed vehicle lighting appears to be technically impossible or prohibitively expensive.

Contents

1. Age-Related Problems in Traffic

The goal of this report is to analyze, on the basis of existing literature and general knowledge, whether there are any specific problems with present vehicle lighting systems (illumination, signaling, conspicuity, and interior) with regard to old road users, and if so, to propose lighting modifications or measures intended to counterbalance such age related problems.

The first two chapters are designed to form a background for the main part of the report. These two chapters will summarize our present knowledge concerning changes in population age, changes of exposure in traffic related to age, accident risk, reasons for the change in accident risk, changes in central capacity and peripheral capacity (mainly vision) related to age, and suggested countermeasures to overcome or reduce the age related problems.

There is no clear cut-off age between middle-aged and old persons. For example, one categorization uses the following distinctions: young old (50-60), medium old (61-70), and old (over 70). Furthermore, from the functional point of view "old" varies quite substantially depending on the task.

Aging is sometimes divided into physiological, cognitive, and social aging. In this report we are mainly concerned with physiological and cognitive aging. However, we cannot totally disregard the sociological aging, because it influences both the need for transport (and thereby the exposure to accidents) and also the willingness to take risks.

1.1 Road-user age, exposure, and road accident statistics

The proportion of old persons varies considerably between countries. In the so-called developed world, it is generally high. In North America and Europe, the proportion of persons over 60 years of age is about 15 percent and is increasing rapidly. In the year 2020 the proportion is expected to be about 20 percent. In many of the developing countries the figures are somewhat different. In South Asia and Latin America the corresponding figures are about 6 percent now and will be about 10 percent in the year 2020. In Africa the situation is predicted to be relatively stable at about 5 percent (OECD, 1985).

Partly as a consequence of this population change—and partly as an effect of a raised standard of living, improved health status, and level of education—the proportion of active license holders and drivers in the older age groups will increase even more rapidly.

It is well established that road users change their travel pattern over age. These changes depend on factors such as the nature of the society, level of motorization, transportation infrastructure, and the extent of public transport.

When the changed exposure to road traffic is included, the risk of having an accident and the risk of getting injured or killed is related to age in a U-shaped way. In other words, the risk per mile traveled is lowest for the middle-aged.

The human body gets more and more fragile with increasing age, and the possibilities to repair and rehabilitate an injured person are also reduced with increasing age. Therefore, each accident involving an old person has more severe consequences than an analogous accident involving a young person. One way of expressing this is to state the number of fatalities per 1000 crashes. This figure is fairly stable at about two from the age of 15 to the age of 65. But then it increases very steeply. At 70 it is about three, and at 80 about six (NHTSA, 1993).

Old road-accident victims also have a higher degree of hospitalization. Stays over 20 days are about twice as frequent for old victims as they are for young victims. Compared with the age group 25-44, those between 55-64 spend 50 percent longer in a hospital, those between 65 and 74 about 100 percent longer, and those over 74 more than 100 percent longer (van Kampen, 1989).

In summary, these facts show that there are safety problems associated with old persons in traffic, and that in most countries these problems are going to increase in the coming years.

1.1.1 Drivers

The average driver reduces the amount of driving when he or she gets older. In broad terms, the annual mileage for the group above 65 is, on average, about one-third of the annual mileage for the 25-64 group. However, since the number of old drivers increases steadily, the total amount of miles driven by old drivers is increasing every year much more rapidly than the mileage for any other age group (Sivak, Campbell, Schneider, Sprague, Streff, and Waller, 1995). In spite of the average, reduced, annual mileage, the number of trips made by the average old driver is not reduced to the same extent. In other words old drivers seem to make frequent but short trips.

Furthermore, the quantitatively reduced driving distances are accompanied by qualitative changes. Old drivers restrict their driving under certain circumstances. Typical conditions avoided by old drivers are winter driving, night driving, and rush hour driving (OECD, 1985).

A Dutch study reports that the five most frequently reported problems by drivers aged 55 and over were glare, rain, darkness, driving backward, and parking in narrow spaces (Opmeer, 1955).

Sabey (1993) reports on solutions chosen by old British drivers to counteract some of their problems. The most frequent action is to leave more distance to the vehicle in front (60 percent of persons over 75 years of age), followed by being more cautious (57 percent), avoiding rush-hour traffic and heavy traffic (50 percent), avoiding long trips (50 percent), and avoiding night driving (46 percent).

There are also indications of changes in driving behavior with age. Studies have shown, for example, that in comparable conditions old drivers tend to choose a lower speed than do young drivers.

The relative increase in fatal accident risk for drivers above 65 is about twice that of all driver age groups and corresponds to the risk for drivers under 25. Furthermore, old drivers are found to be even more culpable for accidents than their accident involvement would predict (Sivak et al., 1995).

Another qualitative difference between accidents involving young and old drivers is the types of accidents. Old drivers are overrepresented in intersection accidents, such as crossings, especially those involving left turns (Garber, 1990; Viano, 1990; Hakamies-Blomqvist, 1994). Old drivers are also overinvolved in accidents related to traffic-control situations, especially at stop signs (Garber, 1990; Hakamies-Blomqvist, 1994). On the other hand they are underrepresented in single vehicle accidents, speeding accidents, and alcohol-related accidents (Rompe, 1990; NHTSA, 1993; Thulin, 1997).

The involvement rate in fatal crashes is much higher at night relative to daytime except for the very old drivers (above 70). The largest differences between day and night are for the young drivers, while the smallest differences are for the old drivers. However, for both day and night, the involvement in fatal crashes increases in the U.S. with increasing age. At night, the increase starts at about 65, while in daytime it starts about 60 (see Figure 1). The rate increase is much steeper for daytime than for nighttime. For old drivers, the day and night rates are roughly equal. During nighttime male drivers have a much higher involvement rate than females in fatal crashes below the age of 25, a higher rate between 25 and 65, and a slightly lower rate above the age of 65 (Massie and Campbell, 1993).

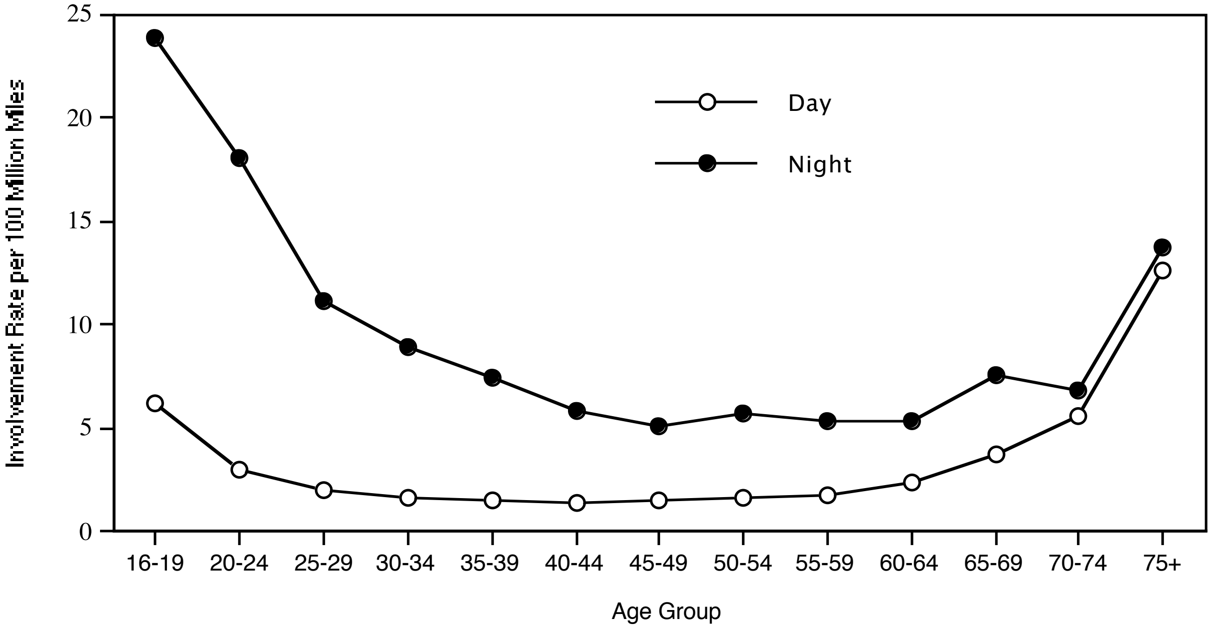

Figure 1. Age and fatality rates by time of day. (Adapted from Massie and Campbell, 1993.)

Swedish data give a somewhat different picture (Thulin, 1997). While the involvement rate of the young drivers (18-24) is more than three times higher during nighttime than during daytime, the rate for the old drivers (65-84) is not increased during nighttime and it is about a tenth of the rate for young drivers during nighttime.

German data lie somewhere between the U.S. and the Swedish (Temming, 1993). The highest night-accident rate and accident increase was found for young drivers and the lowest for middle-aged drivers. There was no difference in accident rates of middle aged and old drivers in bright daylight, but the old drivers had higher involvement rates in situations with lower illumination.

The Swedish data show higher involvement rates for nighttime. Single vehicle injury accidents do not show an overinvolvement of old drivers. One of the reasons for this difference between U.S. and Swedish data is probably that the Swedish results are based on the time of the accident (11p.m.-5a.m.) while the U.S. data are really based on the actual ambient lighting condition.

Old drivers are typically overrepresented in multi-vehicle crashes (in which the vehicle of the old driver is hit from the side or in the rear), and single-vehicle crashes (in which the driver runs off the road) (Mortimer and Fell, 1988).

Old drivers are also reported to be heavily overrepresented in responsibility for crashes (Cooper, 1989). At about the age of 75 the probability of responsibility is twice as high as for the age group 25-65, and it is about equal to that of the 16-year-old group. At higher ages this probability of responsibility increases very fast. At 85, it is three times as high as the age group 25-65.

The above description gives the impression that traffic accidents and fatalities comprise a large and serious health problem for the old driver. We should, however, put this traffic-focused description in a larger perspective. Then it becomes obvious that for the older driver, road-traffic accidents are really a comparatively small health problem. The main reason for this is that all the other health problems, such as cardiovascular diseases, increase so much faster with higher age. Another reason is that traffic accidents, but not diseases, are perceived to be responsive to influence on the individual level.

The above discussion may also give the impressions that old-driver crashes constitute a serious problem to society. However, this is not quite the case. Because old drivers limit their driving, their total number of crashes is low and the cost for society is also comparatively low. In the Australian state of Victoria, it is estimated that the society costs for old (>64) driver trauma is only about 5 percent of total driver trauma costs (Fildes et al., 1994a) in spite of the higher hospitalization and lower rehabilitation among old persons.

Table 1 (adapted from Thulin and Nilsson, 1994) provides a good illustration of the role of age in the magnitude of the problem in Sweden. Table 1 includes age-related data on exposure (column 2), accident risk (column 3), and consequences of accidents (column 4). A product of these three parameters (column 5) can be viewed as a public-health index of the magnitude of the safety problem. As can be seen from Table 1, from this point of view there is no “old driver” problem.

Table 1.
Exposure, risk, and consequences for car drivers of different ages.
(Adapted from Thulin and Nilsson, 1994.)

Age group	Exposure (million person km)	Risk (injuries per million person km)	Consequences (fatalities per injuries)	Exposure times risk times consequences
18-19	1,815	.474	.034	29.25
20-24	4,025	.428	.027	46.51
25-34	12,149	.184	.029	64.83
35-44	13,765	.121	.025	41.64
45-54	16,782	.076	.031	39.54
55-64	8,929	.090	.045	36.16
65-74	5,824	.102	.048	28.51
75-84	940	.322	.073	22.09

1.1.2 Other road users

While there is a substantial amount of international data on old drivers, the age-related data on the travel patterns and accident involvement of other road users is relatively sparse.

The total annual distance traveled per person by all modes of travel varies from country to country. But typically, persons in the age group 25-64 years travel about three times as far annually as persons in the age group 65 and over (OECD, 1985; Massie and Campbell, 1993)

With increasing age, the amount of travel carried out as a pedestrian, as a car passenger, on public transport, and on bicycle increases, while the amount of travel as a driver decreases. Still, about 30 percent of the distance traveled by those over 65 is made as a driver (OECD, 1985).

There are some major differences between Europe and the U.S. in the availability and use of public transportation. An American citizen travels on bus and subway less than half the annual distance of an average European. While in Europe the absolute distance traveled on bus and subway increases with increasing user age, it decreases in the U.S. to about one tenth of that of a European over 65 years of age (OECD, 1985).

For pedestrians, the differences between the two parts of the world are even more pronounced. In the U.S., the annual distance traveled as a pedestrian in the age group 25-64 is about one sixth of the average European (and Canadian!). In Europe, for the pedestrian 65 and above, the absolute annual distance is unchanged. In Canada it is more than halved, and in the U.S. it is about one tenth of the corresponding European figures (OECD, 1985).

For bicycles, the differences between countries are even more pronounced than for public transportation and pedestrians. The leading European country for bicycle travel is The Netherlands.

There, an average bicyclist in the age 25-64 travels almost 1,000 km annually. This is almost halved for the 65-and-above age group. The absolute figures vary among other European countries, but the decrease in annual bicycling for old persons is generally similar. In the U.S. the average person in the 25-64 age group travels by bicycle an annual distance of only about 10 km. For the old-age group, this is further reduced to about 3 km (OECD, 1985).

There are few data on the risk of unprotected road users as a function of age. Some information is available for Sweden (Thulin, 1997). Those data show that for pedestrians the injury (including fatality) risk per million person km is fairly stable up to about 65 years. In the group 65-74 it is roughly doubled and for the age group 75-84 it is seven times higher than for the 13-64 group. There are no sex effects up to the age of 18. Between 18 and 64 the risk for females is about half of the risk for males, but it is about 40 percent higher for the males in the 65-and-older age group.

A British study gives a similar picture (Grayson, 1980). Pedestrian casualties in relation to number of roads crossed are fairly constant up to the age of 60. At higher ages, the risk rapidly increases, and it is seven times as high for pedestrians at 80 and above.

Grayson also provides information about the risks for cyclists as a function of age. The risk of cycling is about twice as high as for walking. From 13 years to about 65 years the fatality risk per million person km is fairly stable. For the group 65-74, the involvement rate is about doubled, and for 75-84, it is about three times as high. Among the old injured and killed cyclists, the risk for males is higher than that for females relative to the pedestrian situation. Speed may be a factor here.

There are age-related changes in the accident patterns of unprotected road users as well. Salusjärvi and Mäkinen (1985) report that of the pedestrians killed in Finland, 16-17 percent among the young and middle-aged (0-64) were killed on marked pedestrian crossings, and the rest outside marked crossings. But among the old pedestrians (>64) the proportion killed on marked pedestrian crossings was twice as high (35 percent). Among the cyclists killed there was no difference between age groups in the crossing accidents (excluding turning), but for left hand turns the proportion killed in ages 0-64 was about 15 percent, while the corresponding figure for the old (>64) was again twice as high (29 percent).

Data concerning involvement of old unprotected road users at night also exist for the U.S. (Zegeer et al., 1993), Australia (Fildes et al., 1994a), and Sweden (Thulin, 1997). According to Zegeer, over 80 percent of the fatal pedestrian accidents for the age group 15-44 occur in darkness. For the age group over 75 this proportion is reduced to 40 percent. The results show that there is an overinvolvement of old pedestrians (>55) in road accidents during the day and an underinvolvement of the old pedestrians during the night. This is mainly a consequence of the variation of exposure (Thulin, 1997). The risk (per million person km) of death or injury in night traffic accidents over all age groups is much higher than during the day. For pedestrians, it is about six times as high, and for cyclists it is about four times as high.

The injury pattern also changes with age and mode of traveling (van Kampen, 1989). Old (>55) car occupants have roughly equal numbers of head and thorax injuries, while the comparison group (25-44) have far more head injuries. Old cyclists on the other hand, suffer almost twice as many head injuries as leg injuries, while the situation is reversed for the 25-44 group. For the pedestrians, the injury pattern looks very much the same for the old group and the 25-44 group. Head and leg injuries are the two largest groups, and they are about equal in frequency.

The population groups that are really using public transport (primarily bus) are young persons and old women (Thulin, 1997). For young persons, it is, to a large extent, in the form of transportation to and from school. For old women, it is often the only alternative. Actions to increase public travel among the old have dealt with a variety of issues, including regularity of service, step height, improving the process of getting on and off, and costs (Fildes et al., 1994b). But some bus systems have difficulties in meeting the demands of the public. Furthermore, the public often requires more than bus systems can deliver. Prices have gone up more than the costs of driving a car, distances traveled by buses have increased, but passenger km have decreased and more subsidies are needed (Bayliss, 1993).

In developed countries, travel by bus is safer than travel by car by a factor of 10 (Evans, 1993). However, travel by bus, train, or subway normally requires some other means of transportation to and from the start and end points. Frequently this is done by walking or bicycling. Consequently, a trip taken by public transportation is, as a whole, often not safer than going by car. What needs to be improved from a safety point of view in public transportation are the stop areas where the passengers are embarking and disembarking, and the transportation to and from the stop areas. Still another safety problem with buses and trams is the risk they create for the unprotected road users.

The fragility of old persons shows even more clearly for pedestrians than for drivers. The likelihood of a serious or fatal injury given a crash in Australia is 54 percent for old pedestrians, compared with only 19 percent for young (<64) drivers (Fildes et al., 1994a).

In absolute numbers road accidents are steadily decreasing with increasing age for all categories of road users. If a risk is calculated using some kind of mileage in the denominator, the risk curves for both drivers and pedestrians show a U-shaped relation with age. If, on the other hand, population is used as the denominator instead of mileage, the road-accident casualty rate for drivers steadily decreases with increasing age. For pedestrians, however, it is again U-shaped although not as markedly for the mileage as the denominator.

1.2 The effect of aging on various non-visual functions

In this section, a summary is given of the types of arguments presented in the literature to explain the overinvolvement or underinvolvement of old road users in road accidents in general or in specific types of accidents. Drivers and other road users are treated together, because they suffer from the same problems. The differences are mainly that the driver is in charge of more energy and is normally more pressed by time. Therefore, the driver’s mistakes could be dangerous not only to himself but also for other road users. The countermeasures are different mainly because the motor vehicle offers greater possibilities for legislative measures.

Our understanding of aging is far from complete. It is believed that aging is mainly genetically coded. But, the physical and social environment can, to a certain degree, influence the aging process. Smoking is a good example of that.

Aging is a continuous, irreversible process. It is arguable when growing stops and when aging starts. The effect of aging is that the capacity of the organism to adapt to new situations is gradually reduced. Because it is a continuous process, it is very hard to set specific thresholds in terms of chronological age.

A major issue in aging is variability. There are two types of variability. One type is within-person variability. One individual may be “old” in his vision but “young” in his hearing or vice versa. Another type of variability is between-person variability. At a given chronological age, one individual may be quite “old” in his behavior while another one is quite “young.” In general, between-person variability increases with age.

The vital functions (e.g., cardiac output, lung capacity, and nerve conduction velocity) decline at a rate of about 1 percent per year from the time when the retrogression starts. However, from a road user’s point of view, the functional capacity of cognitive, sensorial, perceptive, and motor functions are much more important. Reductions in these functions are believed to be the main reasons for the increased risk of old road users. However, exactly what the relation is between decreased functional capacity and accident risk is not clear.

One basic cognitive problem appears to be related to the complex time pressure of the task and the time pressure to solve the problem. Old persons tend to require more information and more time to make a safe decision. Old persons are more easily distracted, have difficulties in attending to or remembering the most important stimuli, and have difficulties in dividing or shifting their attention between several stimuli (Fildes at al., 1994b; Sivak, Campbell, Schneider, Sprague, Streff, and Waller, 1995).

As is pointed out in Sivak et al. (1995), driving for the experienced driver is to a large extent an automatic process and automatic processes are more resistant to aging than controlled processes. On the other hand it is more difficult to acquire new automatic processes with increasing age. Old drivers should therefore try to use automatic processes and avoid controlled processes. We do not know, however, how to facilitate such automatic processes, and how the transition from one mode to another one occurs. One hypothesis is that the visual system is testing what the cognitive system is predicting, and when the predictions turn out to be wrong the process is changed from automatic to controlled (Rumar, 1990). If that hypothesis is correct, it puts somewhat lower requirements on the visual system of old persons (who are experienced predictors) than if vision were the only primary information source. On the other hand, there might be problems for the old person when an unpredicted event happens.

Reflex and reaction times increase with increasing age. Reaction or decision times increase with increasing numbers of alternatives (with increased complexity). The increase is more pronounced for old persons (Temming, 1993; Sivak et al., 1995). However, the more a reaction is dependent on experience and preparation, the smaller is the difference between young and old persons. A completely inexperienced young person may even have longer reaction times than an experienced, but quite old, person.

In addition to these central effects of normal aging come *pathologic* problems, such as dementia and Alzheimer's disease, which increase rapidly after about 65 years of age. These syndromes affect higher order cortical functioning, and it has long been realized that they influence road user behavior. Johansson (1997) has studied this problem. He has designed a visual test, based on dynamic visual acuity, to diagnose Alzheimer victims at an early stage in their disease. His conclusion is that while dynamic visual acuity does not differentiate generally between high-risk drivers and safe drivers, it does work as a differentiating test for old drivers with Alzheimer problems.

Muscular or motor functions are also influenced by age. Muscular strength decreases rapidly after about 60 years of age. Mobility, especially rotation of the neck, is reduced with increasing age. Joint flexibility decreases with higher age. The degree of this decrement is, however, dependent on the particular joint. Manual dexterity, which is needed especially for handling automotive controls, is impaired with increasing age (Sivak et al., 1995).

Hearing is one of the body's basic alarm systems. It has 360-degree coverage, the shortest reaction time and is alert at all times. It progressively loses its capacity for stimulation and communication. Higher frequencies are affected the most (Temming, 1993). Hearing also plays a role in balance and in the perception of the physical and emotional environment. It is not totally independent of vision.

Hearing is of secondary importance for present day drivers in well-insulated vehicles. Often drivers cannot even hear their engines. Only strong and near horn signals get through to the driver. Even emergency vehicles have problems making their presence known by sound signals. On the other hand, hearing is a very important sense for unprotected road users, especially pedestrians and bicyclists, who need to hear approaching vehicles. Therefore, they should not wear portable sound systems when in traffic.

Old pedestrians with reduced hearing often get surprised or hit by "silent" bicyclists coming from behind. The same cause is probably behind old pedestrians frequently stepping out into the street immediately in front of a bicyclist, although in this case there are probably also cognitive reasons for their behavior: They might be looking for the greatest danger—the car—and therefore they do not see the bicyclist (see visual search below).

Vision is no doubt the most important sense for road users. There are many claims that 90 percent of driver information is obtained through vision. However, as Sivak (1996) has shown, there are no studies that can substantiate such a precise figure. Experiences from simulators show that in locomotion vision is critical. The importance of vision, of course, varies with the task that the road user has to carry out. To begin with, it is an alarm system backing up the hearing. Sivak et al. (1995) gives a good summary of the problems that old persons have with vision, perception, and attention. Visual problems associated with road users will be treated in section 2 of this report therefore they are not further dealt with here.

1.3 Previously proposed countermeasures to reduce the high accident rate of old road users and to compensate for their functional problems.

1.3.1 Drivers

Around the world governments and individuals have concern for the environment. Consequently, efforts are made to try to limit or restrict the use of private automobiles. It is probably the case that it will be easier to persuade the young generation to do so than it will be to persuade the older generation (with well established habits of using the car) to do so. (Although, as is evident from the above, they may have other reasons to do so.)

Based on age-related decrements in central functions (e.g., divided attention, processing and decision times, memory) and peripheral functions (e.g., visual acuity, glare recovery, peripheral vision), the accident rate and the accident involvement of old drivers would be expected to be much higher than it indeed is. (The increased frequency of diseases, reduced mobility of parts of the body, and more intensive use of medications further reduce old drivers' capacity.)

It is obvious that old persons restrict their driving to avoid situations and conditions that they experience as difficult or dangerous. Without that type of self-imposed restriction, the situation would likely be much more serious. However, mobility is an important aspect of life even for old persons. Partly it is, of course, a matter of habit. But mobility is needed not only to access specific goals, but more generally as a matter of independence and freedom—a quality of life.

One general observation that explains some of the comparatively low accident rates of the old drivers is that they tend to drive slower, especially in situations they experience as being difficult. It is well known that speed is the most important variable for safety in road traffic. It has often been stated that driving is a self-paced task. Observations show that this is true, but most drivers reduce their speed too little to compensate for an increased difficulty in the driving task. One question is whether old drivers differ from the average driver in this respect. The fact that they abstain from difficult situations more than young drivers do indicates that that could be the case.

In other words, we seem to be in a situation that is difficult to solve by restricting the driving of old persons or by providing them alternative possibilities to the car to maintain their mobility. A solution based on individual public transportation would also be very expensive, as the car is unsurpassed as an individual means of transportation. Since there are other much more pressing problems with old persons in society (e.g., treatment of various diseases), there is not a very strong motivation in society to invest heavily in special modes of public transportation for the elderly. Sweden was one of the countries that had high ambitions in this field. For economic reasons it was however, necessary to reduce this type of effort.

Another reason for not trying to prevent or restrict old persons from driving is that their need for mobility will still be there and they will fill that need in other ways (e.g., by walking or cycling). As has been shown above, the alternative transportation modes often show higher accident rates than do automobile driving (Bernhard, 1991). A comparison between the situation in Finland with stricter licensing rules for old drivers and Sweden with more liberal rules indicates that preventing old persons from driving will result in an increased casualty rate for them and for the system as a whole because they will walk and bicycle more (Hakamies-Blomqvist et al., 1996).

Therefore, another counterstrategy that should be further investigated is to design the traffic environment, the rules, the legislation, and the automobile in such a way that the various deficiencies of old persons as road users are compensated for. Graduated licensing not only for young persons but also for old persons is another untried proposal (Graham, 1995). Information, education, and training of old drivers are still other possibilities.

Below are the most commonly suggested measures to reduce the high accident rate of old drivers, and to compensate for their functional impairments (OECD, 1985; Fildes et al., 1994b; Sivak et al., 1995; Maycock, 1997):

License reexamination. The validity and reliability of present license examinations are not very impressive. Thus, it is not clear how useful it is to repeat the same process at a higher age. On the other hand, if the goal is to make old persons realize their own problems and to question themselves whether they should continue with driving, then it could be a good idea.

Information and education. This is again a measure that is generally not very effective, because it is difficult to reach the persons that really need it. However, in the case of old persons this approach could prove to be more successful.

Improvement in the roadway environment (including sign, signal, and rule systems). This is generally supposed to be the most effective method in the long run. It is, however, the most expensive in the short run, and that is, unfortunately, what too often is decisive. The main idea is to reduce complexity in the infrastructure (e.g., by separate lanes and signals for turning traffic and by increased size and brightness of markings, signs, and signals).

Automobile improvement (both inside and outside). Common proposals here are designs aimed at reducing the consequence of a crash (e.g., side air bags and better crash compatibility between different types of vehicles), facilitating ingress and egress, reducing the need for extensive driver motion (e.g., improved rear vision), and facilitating the reading of instruments and handling of controls. Other proposals deal with the lighting and signaling systems, and they will be treated in the next section.

1.3.2 Other road users

As shown above, the unprotected road users have a substantially higher accident and injury rate than the car occupants. This is the case in spite of the fact that most old pedestrians and bicyclists as well as drivers restrict their travel as much as they think they can. However, walking is normally the last mode of transportation to be relinquished (except for using a taxi).

The most commonly suggested measures to reduce the high accident and injury rate for unprotected road users and to compensate for their functional impairment are as follows:

Information and education. These measures should have two target groups, old persons and all drivers, because it is normally driver behavior that is the problem for old pedestrians and bicyclists. And still, based on earlier experience of information and education campaigns, this approach can be expected to have limited effectiveness.

Improvement in the roadway environment (including signs, signals, and rules). Again, this is the approach that is expected to have the largest potential. The general idea is to keep pedestrians and cyclists separated from each other and, primarily, from automobiles. That is easy to say and expensive to do. Other ideas concern lower speed limits, longer and safer (no turning traffic) traffic-signal phases, and street islands to make it possible to cross streets in two shorter parts. Also for cyclists, which from many viewpoints are a group that lie in between vehicles and pedestrians, road crossings and intersections are the main problem. Except for the street islands, they have largely the same requirements as the pedestrians.

Vehicles. The exterior of many types of motor vehicles should be modified to minimize the injury consequences of a collision with a pedestrian or a cyclist. Improved public transportation would reduce dangerous exposure of walking or cycling. Buses should be modified in many respects to facilitate usage by old persons. Some of them have to do with safety (e.g., handlebars to prevent falling during acceleration and deceleration).

2. Age-Related Vision Problems

Schieber (1994) provides an excellent and extensive review of literature in this area. The following summary is based primarily on his review.

2.1 Age and vision

2.1.1 Anatomical changes

One of the earliest observations about age-related differences is that the diameter of the pupil under dim conditions will not open as much in old persons as it will in young persons (about 4 mm versus about 7 mm; Lowenfeld, 1979). Earlier this was considered to be detrimental for vision only under lower levels of illumination. However, new studies have shown that the small pupil might even be beneficial for the old because it reduces the negative effects of their optical deficiencies (Sloane, Owsley, and Alvarez, 1988).

Accommodation is another problem for old persons. The near point for sharp vision gradually moves out after about 40 years of age, when it is about 20 cm, to about 100 cm at the age of 70 (Temming, 1993). However impaired accommodation is a good example of how deficiencies can be compensated by a technological solution—eye glasses.

Data show that with advanced age the number of cones in the fovea (central vision) is not reduced, but the number of rods in the near central vision is (Curcio, Millican, Allen, and Kalina, 1993). Is impaired peripheral vision a reason for deteriorating visual guidance of old persons at lower levels of illumination? (See Owens and Andre, 1996.) Contrary to earlier beliefs, the neuron density does not decrease with increasing age (Leuba and Garey, 1987).

2.1.2 Dark adaptation

The purpose of dark adaptation is to increase visual sensitivity. It is a slow process, but it does not slow down further with increasing age. The eventual asymptotic level of sensitivity changes by about 0.1 log units for every decade of age (Eisner, Fleming, Klein, and Mauldin, 1987). However, there are substantial individual differences here.

2.1.3 Visual acuity

There are extensive data showing the decay of visual acuity with age (e.g., Frisen and Frisen, 1981). Age-related decay is greater at low luminance and low contrast conditions. For very old persons this change is substantial.

Extensive studies in the sixties showed no relation between static visual acuity and driving performance, and recent studies have come to the same conclusion. However, none of the studies really pressed the drivers to the limit; all of them involved normal driving without any critical situations.

Myopia is a common visual deficiency that reduces visual acuity. It is normally compensated for adequately correction glasses. There is however, a special type of myopia that occurs in situations with low levels of illumination. It is called night myopia (Owens and Leibowitz, 1975). While night myopia can be corrected, such correction is seldom carried out.

Sayer et al. (1997), in a study of hydrophobic windshield coating, found that visual acuity in a night driving situation was worse than during the day for both young and old drivers, but old drivers' acuity was worse than that of young drivers in both conditions.

2.1.4 Dynamic visual acuity (DVA)

When DVA is measured, the target is moved at successively higher speeds perpendicular to the subject. There was great hope in the seventies that DVA would turn out to be the critical measure of driver vision. However, the early results (Burg, 1967) were statistically significant not because the effect was strong but because the number of subjects was so huge (>17,000). There are age differences, but these are not very strong. Furthermore the differences seem to decrease when age-related differences in retinal illumination are compensated for.

2.1.5. Contrast sensitivity

Visual acuity is measured by testing the ability to identify successively smaller details. Contrast sensitivity can be effectively measured by keeping the size of the details constant and successively reducing the contrast between detail and background. Noy (1985) argues that contrast sensitivity may be the missing link between vision and driving.

Contrast sensitivity is one of the most important visual aspects for night traffic. It has been known for a long time that contrast sensitivity degrades with increasing age. However, only recently has it been established that this is not purely an optical effect, but also a neural effect (Elliot, Whitaker, and MacVeigh, 1990). Consequently, various types of optical-aid systems do not completely neutralize this fairly strong effect.

Seeing with two eyes results in better performance than seeing with only one eye. This is called binocular summation. Tests have shown that binocular summation does not work as effectively for old subjects as it does for young ones. Degradation of the temporal and spatial summation may be a factor in decreased visual performance among the elderly.

Low contrast sensitivity appears to be related to driving performance, and especially so for old drivers (Owsley, Sloane, Skalka, and Jackson, 1990). Drivers suffering from low-contrast sensitivity often mention the following five major problem areas (Schieber, Kline, Kline, and Fozard, 1992):

- unexpected vehicles in the peripheral visual field
- too dimly lit instrument panels
- uncertain estimation of vehicle speed
- difficulty seeing through windshield
- inability to read road signs

Traffic control devices such as signs and markings require a certain contrast to be detected and read. Due to the changes in the eye with increasing age, this requirement is often not fulfilled for old drivers. Staplin et al. (1989) found that a typical old driver needs approximately 50 percent more contrast to read a sign than does a young driver. Old drivers with 25th percentile vision may even require 10 to 20 times greater contrasts. Old drivers suffering from cataracts performed significantly worse than the young and the old without cataracts on a number of driving tasks. Contrast sensitivity proved to be the best predictor of poor drivers. Contrast sensitivity also differentiated between persons who could and could not read signs accurately. The inclusion of age-related contrast data into a headlight visibility model resulted in a greater loss in the predicted detection distances than the inclusion of age-related glare data.

2.1.6 Dynamic contrast sensitivity

Age-related differences in contrast sensitivity have also been shown for moving targets. Reduced effectiveness of pursuit eye movements is a likely contributor to this effect (Elliot et al., 1990).

2.1.7 Eye movements

The ability to fixate up and down is gradually reduced with increased age, from about 45 degrees to about 30 degrees (Huaman and Sharpe, 1993). The eye movements that have the purpose of either bringing a target into the center of vision (saccadic movements), or keeping it there (pursuit movements) are also negatively affected by age (e.g., Wacher, Buser, Bernhard, and Lachenmeyr, 1993; Sharpe and Sylvester, 1978). The saccadic movements have a larger latency (especially under lower levels of illumination), are slower, and more of them are needed to engage peripheral targets. Old persons cannot maintain pursuit movements for faster targets. Both types of movements suffer more in complex situations.

Saccadic eye movements are shorter and fixations are longer during nighttime than during daytime (Cohen, 1986). The fixation pattern in front of the vehicle changes with the geometry of the road and, in night driving, with the headlamp beam (Graf and Krebs, 1976).

2.1.8 Peripheral vision

It has long been known that visual acuity decreases with eccentricity of the target. The decrease is rapid at small angles. At one-degree eccentricity the visual acuity is only half of that in the fovea (Ludvigh, 1941), but thereafter the decrease is more gradual. The rate of loss in visual sensitivity accelerates with increasing age (Collin, Han, and Kohr, 1988). The decrease of useful visual field in terms of visual acuity is considerable. The same type of age effects has been noted for contrast sensitivity (Crassini, Brown, and Bowman, 1988), and for visual search (Sekuler and Ball, 1986). Losses in visual search are, however, probably a consequence of cognitive and attentional changes.

Several studies have shown that large losses in visual field influence driving performance (e.g., Hedin and Lövsund, 1986). However, some individuals seem to develop compensatory scanning behavior that is partly successful (Lövsund, Hedin, and Törnros, 1991). Artificially restricted fields of view did not influence simple straightforward driving. But it reduced the speed, impaired identification of road signs, and made it more difficult to avoid obstacles, to maneuver through narrow openings, and to maintain the accuracy of lane keeping and of reversing. This seems to support the hypothesis of two visual systems, one for guidance and one for recognition (Owens and Andre, 1996).

2.1.9 Distance, motion, and speed perception

Classic depth perception, based on retinal disparity, is generally not influenced by age. However, depth perception in road traffic is more dependent on other types of cues (e.g., gradients and parallax), and for these functions there are no good studies. This is unfortunate because other studies indicate that distance cues seem to be used more by old drivers than by young drivers.

There are substantial age differences (by a factor of two) in sensitivity to simple movements such as oscillatory movements (e.g., Buckingham, Whitaker, and Banford, 1987). These effects are probably of neural origin. Also more complex, but still artificial, motion sensitivity, such as detecting when dots are moving irregularly over a large area where more and more dots successively have a common motion direction, show a factor of two difference between old and young subjects (Trick and Silverman, 1991). More natural motion tasks, such as sensitivity to heading in a visual flow, seem to be less sensitive to aging (Warren, Blackwell, and Morris, 1989).

Laboratory studies of sensitivity to speed yield conflicting results concerning age differences. Field studies give somewhat more clear results. For passing cars young subjects seem to underestimate the speed of slow cars and overestimate the speed of fast cars more than do old subjects (Scialfa, Guzy, Leibowitz, Garvey, and Tyrrell, 1991). However, for oncoming cars, fast speeds are underestimated and slow speeds overestimated (Norling, 1963). Norling did not study age differences.

A number of studies have been carried out to test the hypothesis that aging is accompanied by marked declines in motion perception. Old and young subjects' performance in terms of time to collision (TTC), and gap acceptance have been measured and compared in field and simulator studies. Unfortunately, the results are conflicting and difficult to interpret.

Kaukinen (1972) found in a study of overtaking behavior that old drivers made more mistakes (decision errors) during nighttime, while young drivers made more mistakes during daytime. As an anecdotal aside, of those drivers not committing any overtaking errors, 100 percent were married, while among those committing one or more errors only 43 percent were married. The countermeasure seems obvious—get married!

2.1.10 Glare and glare recovery

The main aspect of glare is the stray light caused by intraocular scattering. Tolerance to glare has been found to decrease exponentially with age, with major changes after the age of 40 (e.g., Pulling, Wolf, Sturgis, Vaillancourt, and Dolliver, 1980). Age-related glare effects are probably due to various diseases that increase with age, primarily some degree of cataract. Glare sensitivity should be tested with low-contrast targets.

The time to recover from glare is a neurochemical process. It is less well studied. However, glare recovery time shows considerable age differences, being two to three times longer for healthy old subjects than for young subjects (Schieber, 1994). For persons with retinal diseases the glare recovery time is probably even longer (Collins, 1989).

2.1.11 Color vision

There is a considerable decrease in color discrimination with increased age. The errors are primarily within the blue-green shorter wavelengths (e.g., Knoblauch, Sanders, Kusada, Hynes, Podgor, Higgins, and de Monesterio, 1987). Most of these problems seem to depend on reduced retinal illumination due to optical changes in the eye. In other words, most of the problems can be overcome with adequate illumination (Knoblauch et al., 1987).

2.1.12 Flicker

The traditional way of measuring flicker sensitivity is to increase the rate of a pulsating light until it is perceived as fused, not pulsating light. The threshold is called critical flicker fusion (CFF). CFF worsens gradually with increasing age until the age of about 60, and more rapidly thereafter (Wolf and Shaffra, 1964). Flicker sensitivity is also a good test of foveal retinal degeneration, which is a common disease among old persons (e.g., Mayer, Kim, Svingos, and Glucs, 1988).

2.1.13 Visual search

As will be discussed later in more detail, visual search is probably an essential aspect of road-user performance. Visual search appears to have more to do with perceptual and cognitive mechanisms than with pure visual mechanisms. However, because the eye can be considered an extension of the brain, it is, perhaps, artificial to make such a distinction.

It has been shown that the less the difference between target and background and the more complex the background, the more pronounced are the age differences in visual search. It is more difficult for the old person to ignore irrelevant information (e.g., Salthouse, 1991). Overlearned stimuli may be searched in a more automatic way than unfamiliar stimuli. This is potentially relevant because old persons have a large number of overlearned visual skills, and because automatized skills are more resistant to aging (Salthouse, 1991).

Rabbitt (1990) studied the extent to which subjects of various ages could detect their own errors. The results show that simple, automatic errors could be equally well detected by young and old subjects. On the other hand, old subjects were less accurate in detecting and reporting their more complicated, cognitive errors than were young subjects. This is important because without detecting one’s own errors it is difficult to imagine how correction, improvement, or learning could take place.

2.1.14 Divided attention

Old drivers demonstrate slower visual search in complex environments. This age difference is increased in situations with positional uncertainty concerning the target (Ranney and Simmons, 1992). Old subjects (but not young subjects) have been shown to be affected by the introduction of a secondary task (such as counting). The reason for this difference is not quite clear, but it could be a combination of problems with the cognitive task control and problems among the old drivers in coordinating two manual tasks.

In a simulator-based, car following study by Korteling (1994), the accelerator response was reversed on some trials (when it was depressed, the speed would be reduced). The age differences appeared in terms of lane keeping, but not in terms of car following (as was originally expected). Analogous findings were obtained by Alm and Nilsson (1995). They found that the use of a mobile telephone influenced the speed of old drivers on motorway, but not on more demanding two-lane roads.

2.1.15 Useful field of view (UFOV)

Another important aspect of visual search is the so-called useful field of view (UFOV) (Ball and Owsley, 1992). UFOV may decrease both as a result of more complex background and as a result of higher cognitive load. The test consists of three subtasks:

- information processing speed of central targets
- divided attention with one central and one peripheral target
- selective attention with one central and one peripheral target with distracting background

UFOV can be conceptualized as the area over which visual attention operates at any given instant. Research has shown that reductions in UFOV are more pronounced for old subjects, especially when there is time pressure (Ball, Owsley, Sloane, Roenker, and Bruni, 1993).

2.2 Age, vision, and accident statistics

Reinhardt-Rutland (1992) discusses the target-risk theories from the point of view of visual perception. His conclusions are that because conditions with poor visibility to perceive motion are more risky than conditions with good visibility, the target-risk theory is invalid. Visual problems appear to be the most important reason for old persons' decision to stop driving.

Hakamies-Blomqvist (1994) studied the errors that were judged to contribute most to fatal accidents among young and old drivers. Her results showed that the most frequent errors in fatal accidents among young drivers (26-40) were driving errors (error in handling the vehicle). The dominating errors among old drivers (>64) were observational errors (general or specific inattention, and faulty or lacking perceptions).

One of the problems with night traffic accidents is to separate the effects of impaired visibility from the effects of other factors, such as alcohol, drugs, fatigue, etc. Owens and Sivak (1996), by using the fact that ambient illumination changes over the year, managed to separate reduced-visibility crashes from crashes due to other factors. Their results indicate that impaired visibility is a main factor in collisions between a car and unprotected road users, while alcohol consumption is a main factor in other types of fatal accidents at night. Owens and Brooks (1995) found that the increase of collisions between cars and unprotected road users during periods of reduced visibility was twice as high for old drivers (up to the retirement age) as it was for middle-aged drivers.

It would seem self-evident that visual performance and accident rate should be correlated. However, most of the simple visual parameters tested do not seem to be correlated with accidents. The most common visual-performance measure, visual acuity, shows virtually no relation with accidents. When several simple measures are combined, a stronger relation with accidents for old drivers is found (e.g., a combined test of visual acuity, contrast sensitivity, visual fields).

The link between driver visual field losses and accidents has been established. The relation is, however, not simple. As indicated above, some drivers manage to compensate partly for the visual field losses through intensive head and eye movements. Old drivers seem to suffer more than young do from losses in the visual field. Simple tests of visual field do not to correlate with accidents. However, if a task of divided attention is added, the correlation between visual field and accidents increases.

The most promising visual test developed so far is useful field of view (UFOV). Owsley, Ball, McGwin, Sloane, Roenker, White, and Overly (1998) have shown that old drivers with a substantial impairment in UFOV are over two times more likely to be involved in accidents than those with normal UFOV.

A comprehensive and holistic view on visual characteristics and driver performance in night driving is offered by Owens. In a number of studies (e.g., Owens and Andre, 1996) he discusses and tests the hypothesis that the visual degradation at lower levels of illumination affects the two visual systems of recognition and guidance differently. Most of the visual degradation discussed above affects foveal recognition but not ambient guidance, at least not for young subjects. This type of degradation of vision is even more strengthened at increased age. Owens' results seem to indicate that for old persons the ambient guidance vision degrades at night. That could be one explanation why old drivers (but not young drivers) avoid driving at night, although their recognition vision is not much worse than that of young drivers.

In conclusion, the correlations obtained between a number of measures of visual performance and driving accidents are generally weak. One way to reach significant results is to combine a number of visual parameters. If central functions like attention and mental load are also included, even stronger relations occur. However, it is not only the visual tests that should be blamed for this lack of correlation. The criterion (accidents) is very unreliable, even if it is valid. Schieber (1994) proposes that we should move from accident criteria to performance criteria. Researchers have long had that opinion. However, authorities still seem to regard accidents as the only satisfactory criterion.

2.3. Previously proposed countermeasures to compensate for the degraded visual functions of old road users

The same types of countermeasures that have been proposed for general problems of aging (see Section 1.3) have been proposed for visual age functions.

License re-examination. A very good review of the problems and possibilities in the U.S. is found in TRB (1994). License requirements vary from country to country. But in most countries, visual tests include visual acuity and visual field. Very few countries administer other visual tests such as contrast sensitivity, glare sensitivity or useful field of view. More and more countries renew licenses by mail without any tests. Very few countries withdraw licenses at a specific age. Many countries have periodical visual screening or more extensive medical check-ups past a certain age (OECD, 1985). Although such screening might reduce the accident rate for old drivers, because of modal shift it might be negative to the overall safety of the total transportation system (Hakamies-Blomqvist, 1996).

From what has been said earlier, visual screening starting at a specific age should be effective. According to Schieber (1994), such screening would have three favorable effects: to identify and make possible treatment of drivers with poor visual functions; to inform the individual about problems of which he may not be aware; and to withdraw or limit the license for the seriously visually impaired.

Another promising possibility is graduated licensing for old drivers. That means that their driving license could be restricted so that it is not valid for situations in which they would have serious problems, in the same ways as young persons have graduated licenses or curfews.

Information and education. This type of countermeasure could be directed in two ways towards old drivers: to inform them about the potential problems they are facing, and to indicate ways to overcome some of these problems. Importantly, the difference between subjective and objective visual performance increases with increasing age (Ellinghaus et al., 1990). Information and education could also be directed towards the other drivers, informing them about problems of old drivers.

Improvement in the roadway environment (including signs, markings, signals, and rule system). Intersections with several conflicting stimuli are known to create problems for old drivers. Especially in night driving, old drivers have complained about the markings and delineation along roads, in curves, and at intersections. Old drivers have problems reading road signs at night. Partly this has to do with symbol design, but mostly it is the size, luminance, and contrasts that are inadequate.

There is little in the literature concerning several seemingly obvious countermeasures, such as anti-glare screens, brighter road surfaces, street lighting, side post delineators, luminous road markers, and improved markings of critical objects, edges, or points.

Automobile improvement (both inside and outside). The first visual problem in a car is the windshield. One problem is that windshields are often tinted, as are other car windows, to reduce the heat generated by the sun. The present U.S. requirement on windshield transmittance specifies a minimum of 70 percent. Studies have shown that old drivers have problems detecting targets in night traffic when windshields are more tinted than 70 percent (Freedman et al, 1993). However, I believe that for low levels of illumination and for targets with low contrast, any windshield tinting would decrease performance, especially for old drivers. The same goes for the use of tinted glasses in night driving. No studies have been uncovered on the usage and effects in night traffic of spectacles with fixed or photochromatic tint. An early British study (Davison and Irving, 1980) reports that about 4 percent of all drivers and 14 percent of those with corrected vision did wear such spectacles. Since then the popularity of tinted glasses has, no doubt, increased.

Helmers and Lundqvist (1988) and Owens et al. (1992) studied the effect of windshield characteristics. Their conclusions are that tinting and windshield rake angle have negative effects, but that these effects are small compared with effects from dirt and wear of windshields.

In several studies, Flannagan and his colleagues investigated the effect of glare from rear-view mirrors (Flannagan et al., 1990; 1992; 1993). Their conclusions were that reducing the reflectivity of mirrors (in order to reduce the glare from the mirrors) would have some positive effect on driver visibility to targets straightforward, but would have larger detrimental effects on rearward visibility through the mirrors. In Europe, for the flat interior mirror, the glare position is nowadays standard, and for the convex exterior mirrors the smaller image also results in less glare. Therefore, mirror glare seems to be a comparatively smaller problem in Europe than in the United States.

Mortimer (1989) states that old persons need more light, are more susceptible to glare, and need higher contrasts to see as well as young persons. He therefore suggests higher reflectivity of objects, limitation of very high mounted headlights, glare limitations in mirrors, cleaner headlights, improved automatic headlight aiming, and better control of headlight beam distribution.

Staahl et al. (1995) proposed alternative vehicle-illumination systems to help old drivers in night traffic. These systems have the potential to create visibility without causing glare. The systems are UV headlights using fluorescent targets, and near infrared projectors with head-up display.

Legibility of instrument panels is often a target of complaints from old drivers. That type of criticism is likely to be more frequent as advanced technologies become introduced as standard equipment. Poynter (1988) has shown that old drivers require at least two times the contrast of young drivers to have the same glance legibility. This again stresses the importance of contrast in driving. When the task is more complicated (e.g., reading a map) the fixation time of old drivers (>50) is more than 50 percent longer than those of young drivers (<25) (Wierwille, 1990). Also, more complicated tasks are easier to handle if the visual contrasts of the displays are greater. This indicates that overcoming visual problems consumes attentional resources.

Flannagan and Harrison (1994) tested a situation involving divided attention: a map display using a simulated HUD and a pedestrian-detection task. They found a marked decrement in performance among old drivers when the HUD was moved down from the line of sight. Walker et al. (1990) found that a navigational task was much easier for old drivers if some of the information came through the auditory channel. Hanowski et al. (1995) have designed a special instrument to find and categorize the special problems that old drivers may have with new technologies.

Additional age-related countermeasures include rearview vision systems, improved headlights (including polarized headlights), improved signal lights (for improved detection and recognition), improved vehicle conspicuity functions, improved tell-tales and warning lamps on instrument panels, and regular checking of windshield wear and tear.

Other road users. No specific proposals concerning other road users have been found. One suggestion is to put more stringent requirements on the lighting and marking (fluorescent and retroreflective materials) of pedestrians and cyclists.

3. Present Vehicle Lighting and Road User Age

This section describes present vehicle lighting characteristics and compares them against the characteristics of visual performance found in the previous sections to be representative of old drivers. Where do they seem to match? Is there a discrepancy? Are the discrepancies so large that action should be taken to make lighting fall within the visual performance of old drivers?

A general question concerning the elderly in road traffic is whether everything that is good for old persons really is good for everybody. This is often claimed in general terms. Here we will try to analyze that question from a vehicle lighting point of view. Are there any interactions between optimal lighting specifications and age?

3.1 Vehicle lighting: goals, requirements, and reality

In this section, an effort will be made to summarize the tasks that present vehicle lighting is intended to fulfill. Because vehicle lighting can be said to have four major purposes, the section is divided into corresponding subsections: illumination functions, signaling functions, conspicuity functions, and interior functions.

In reality, out in traffic, too many of the lighting functions do not fulfill these purposes. For one reason or another (road geometry, dirt, aging, corrosion, mishandling, design, weather, etc.) the light specifications according to the requirements are not fulfilled or the light does not fulfill the needs of the users and safety may be threatened. We seem to focus too much on the new and ideal conditions and too little on the real light conditions in traffic.

3.1.1 Illumination functions

The main illumination functions on a car are the high-beam and the low-beam headlamps. The high beams are intended for driving on roads without oncoming traffic or street lighting. The hot spot of the high beams, which should be situated around the infinity point, has an intensity of about 50,000 cd. The high beams are supposed to be aimed straightforward parallel with the road surface.

However, here we will concentrate on the low beams, because they represent by far the majority of the vehicle illumination problems. The low beams are intended for driving on roads with oncoming cars or other road users and for driving in lighted areas. They are supposed to be aimed about 1 percent down to avoid glare towards the oncoming driver while maintaining enough visibility for the driver. Low beams are asymmetric, both horizontally and vertically. The so-called hot spot of a low beam, which is normally situated to the right of the vertical (for right-hand traffic) immediately below the horizon (near 2° R, 1.5° D), has an intensity of about 20,000 cd at 12.8 V. There are two main low-beam design principles in the world: the U.S. system, with a softer cutoff, and the European system, with a sharper cutoff. Figure 2 shows the isocandela diagrams for the U.S. and the European low beams based on the median values of 43 U.S. and 37 European low beams (Sivak, Flannagan, and Sato, 1994a). The two types of beam patterns look different mainly in four aspects. The European low beams are more asymmetric, have a sharper cutoff, have less light above the cutoff, and have more light close to the car.

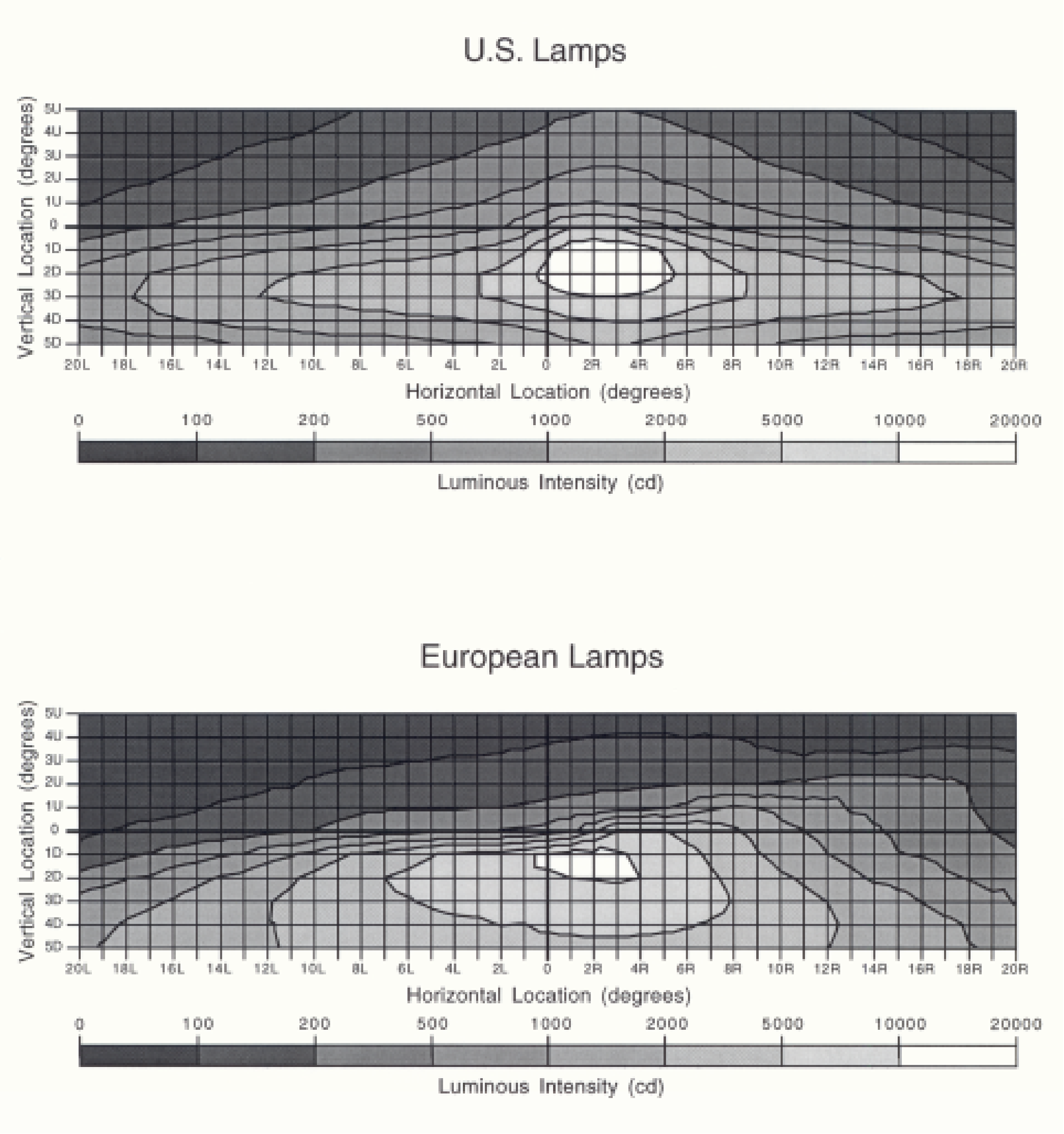

Figure 2. Isocandela diagrams of the median luminous intensities for the U.S. lamps (top panel) and the European lamps (bottome panel). (From Sivak, Flannagan, and Sato, 1994a.)

There are also some secondary illumination functions that are only used in very specific situations. However, they may be of substantial importance in those situations. This group includes the following:

- spot lights to increase the visibility forward when driving on high beams
- front fog lamps to add to or replace the low beams in order to improve visibility in fog
- curve lamps to widen the visibility when driving on low beams (e.g., in narrow curves)
- reversing lamps to offer some visibility rearwards when the driver is reversing

While the high and low beams are standard equipment, the secondary illumination systems are often offered as optional or aftermarket equipment.

For each one of these illumination functions there are fairly specific requirements concerning the light distribution. However, these are conformity-of-production requirements. There are no requirements concerning how much light should reach various parts of the road and the potential targets in actual traffic.

Furthermore the light distribution specifications unfortunately are not harmonized. They are different in different parts of the world both in terms of the locations of the test points as well as the corresponding maximum and minimum values. The three main regulations are ECE/EU (Europe and many other parts of the world), NHTSA (the U.S.), and JSAE (Japan and some other parts of Asia).

However, GTB (an international group of industrial experts on automobile lighting) and GRE (an international governmental group of experts on automobile lighting) are working to try to harmonize the three different international lighting regulations concerning light distributions. The work has come a long way concerning many of the signal and position lamps. Unfortunately it still remains to harmonize the headlight distributions. Preliminary proposals have been presented by a working group within GTB (Sivak and Flannagan, 1994; Moore, 1997). But so far no international agreement has been reached.

As indicated earlier, the primary problem of the vehicle illumination systems is with the low beam. In developed parts of the world low beams are by far the most frequently used beams. The low-beam system is an impossible compromise between good illumination for seeing and low glare towards oncoming road users. Numerous studies have shown that the low beams in many situations do not offer safe visibility distances. The stopping distances are longer than the visibility distances (Olson and Sivak, 1983). The main problem is the construction principle—the dipping of the low beam (Rumar, 1995).

Another problem is aiming. Most of the illumination functions are sensitive to vertical aiming. Because of concerns with energy conservation and other environmental considerations, the electric energy available in a car is limited. Therefore, the wattage of the bulbs used in the illumination devices is also limited. The relevant visual field for the driver has its main extension in the horizontal direction. Only overhead road signs and special road markings (and the roadway itself) are located mostly in the vertical dimension.

Therefore, proper aiming of the illumination lamps is important, especially for the lighting functions that are intended for longer-distance illumination (>50 m) such as spotlights, high beams, low beams, and fog lights. The precision requirements in the vertical direction (where the illumination gradients are much steeper than in the horizontal direction) of the aiming are high (about 0.1 degree). Aiming is, however, sensitive to several common variables such as a change in loading of the vehicle, acceleration or deceleration, and the geometry of the road (vertical and/or horizontal curves).

Some current vehicles have automatic leveling devices intended to compensate for changes in lamp aiming, while other vehicles have manual leveling devices that the driver is supposed to adjust depending on the load distribution of his car. Leveling devices are however, still fairly uncommon. Furthermore if a car is equipped with leveling devices, it only works on the headlamps. If the leveling device works perfectly, it can compensate vertically for the loading of the car but not for any other of the variables influencing headlamp aiming. The main source for misaiming is probably road geometry (Damasky, 1995; Rumar, 1997), for which no compensation is currently available.

Consequently, a large proportion of vehicles have illumination lamps aimed either too low or two high. Recent studies in the Netherlands (Alferdinck and Padmos, 1988) the United Kingdom (Cobb, 1990), and the United States (Copenhaver and Jones, 1992) provide indications of the considerable magnitude of this problem. For example, the Dutch data indicates that mostly because of misaiming, 82 percent of the cars had low beams that gave illumination values below those stated in the regulation. For the reasons stated above (mainly horizontal light distribution with sharp vertical gradients) the lamps are much less sensitive to horizontal misaiming than to vertical misaiming (Sivak, Flannagan, and Sato, 1994b).

Many present cars have high and low beams in one package. Therefore, if one of the light distributions is misaimed, so is other one. The normal procedure in the U.S. and Europe is to carry out the main aiming on the low beams. (In other words, the aiming of the low beam determines the aiming of the high beam. In Japan, the approach is reversed.) None of the other illumination lamps has any leveling system.

Both the spot lights (quite common in Europe), and the fog lights (quite common in the United States; Sivak, Flannagan, Traube, Hashimoto, and Kojima, 1996), are about as sensitive to vertical aiming as are the high and low beams. The curve lights are probably somewhat less sensitive to aiming and the reversing lights are considerably less sensitive.

If the vertical misaiming is too high, the consequence for the driver on high beams is reduced visibility, especially as regards the road surface. For the oncoming driver it probably has no consequence. For the driver on low beams and curve lights, the consequence is better visibility because of greater illumination. That is, however, achieved at the expense of more glare and shorter visibility for the oncoming driver. The decrease in visibility because of glare from lights aimed too high will influence low contrast targets more than high-contrast targets. Even a relatively moderate veiling glare will be enough to make a low-contrast target invisible.

If the vertical aiming is too low, the consequence for the driver on high beams is, again, reduced visibility. That is the case mostly because the illumination straight ahead is reduced, but also because the illumination close to the car is too high. This may lead to eye fixations concentrated closer to the car, and will increase the adaptation level. The high luminance will create a type of glaring veiling luminance. With low-aimed low beams, curve lights, and fog lights, drivers will have reduced visibility, without offering any longer visibility to the oncoming driver because the glare differences of these illumination systems do not vary much, with misaim downward. The decrease in visibility with lights aimed too low will influence low-contrast targets more than high-contrast targets. For example, retroreflective targets will maintain their safe visibility much better than dark-clothed pedestrians.

There is a fundamental difference in light distribution between the European low beams with a sharper cutoff, and the U.S. low beam with a softer cutoff. This difference means that the European low beam is more sensitive to aiming variation, whatever the reason for this variation may be. This sensitivity concerns both illumination for visibility and glare against oncoming road users. The European sharp cutoff means that dynamics of the car will create flashes of high illumination that will increase visibility momentarily but also increase glare during the same periods.

If aiming is the number two problem for vehicle illumination systems, adverse weather conditions is probably number three. There are three main consequences of adverse weather conditions:

- atmospheric problems with transmission and retroreflection or backscattering (e.g., in haze, fog, snow, rain, smoke, and dust)
- road surface problems with high specular reflection (mainly wet road surfaces) with increased glare for oncoming drivers and decreased retroreflection for the drivers
- dirt accumulation on lamps (all types) and on targets (especially signs and markings)

Of the atmospheric conditions, fog is an especially serious problem, which reduces the visibility of the road, and of targets on and along the road. Contrast is wiped out by the reduced transmission and by the increased backscattering of the light from the lamps. Fog lamps reduce discomfort, but often cannot increase visibility substantially. Thick smoke or dust may have the same effects. Snow and, to some extent, rain also create backscattering, but they also generate a very distracting and almost hypnotizing flow in the visual field of the driver.

The specular reflection on wet road surfaces creates problems for all the illumination systems that are based on a downward aiming to avoid glare (low beams, fog lights, curve lights, and reversing lights), because the beam aimed downwards will be mirrored up from the wet, specular road surface towards the eyes of other road users. This indirect glare may be five to ten times as high as the direct glare from the lights. On the other hand the mirror effect will also increase the light intensity towards the potential targets (Hisdal, 1977).

Dirt accumulation on lights will have two effects. A layer of dirt will always reduce the luminous output from the lamp. When the layer is thick, this light reduction will be substantial. In very bad conditions, 50 percent of the light may be lost in less than one hour driving (Rumar, 1974). Thinner layers of dirt (or haze in plastic lenses) may reduce the cutoff of low beams, fog lights, and curve lights and thereby increase the glare from these lamps (Alferdinck and Padmos, 1988; Sivak, Flannagan, Traube, Kojima, and Aoki, 1997). Alferdinck and Padmos (1988) have shown that 87 percent of Dutch cars in actual traffic had glare values higher than those specified in the regulations, mostly due to dirt and aging. Dirt on signs and especially markings may also have very marked negative effects on the visibility of these traffic control devices (Rumar and Öst, 1974, 1975).

The number four general problem is the durability, sensitivity, and reliability of the illumination systems. Traffic inspections and annual inspections have shown that the design of the illumination lamps is not always resistant to various types of normal degradation. Bulb life, scratching and haze of lenses, corrosion of reflectors, and dirt and water in the housing are some of the factors that act to reduce the efficiency of illumination systems in traffic.

Lighting for motorcycles is a special problem. They have considerably lower requirements for their headlights. Furthermore, most of them only have one headlight. This condition, combined with the fact that they are often driven faster than cars, are more vulnerable to unevenness in the road surface than cars, and are tilted to the side in curves (which impairs the effective light distribution), results in additional problems for driver visibility. There is one problem for opposing drivers: It is difficult to recognize whether a motorcycle really is a motorcycle or a car with one headlamp.

Signal and marking lamps seem to be OK, except for the same concern as with the frontal identification. The opposite may also occur—two motorcycles driving side by side may be taken for a car. This highlights the need for a special marking configuration, or a gestalt, which would make it easy to identify a two-wheeler, both from the front, the rear, and the side.

In summary, present vehicle-illumination systems in actual traffic provide much less luminous intensity in the directions of potential targets than was intended when the light distribution requirements were written. This results in lower contrasts and reduced visibility of the potential targets. This also means that present vehicle illumination systems often generate glare levels that are higher than those intended when the requirements were written. When these two detrimental effects (decreased illumination and increased glare) occur at the same time, the visibility reduction becomes substantial and possibly also dangerous.

3.1.2 Signaling and marking functions

Currently, the main signaling functions are as follows:

- to signal that the driver intends to change direction (turn signals)
- to indicate that the driver is pressing the brake pedal (brake lights)
- to indicate that the vehicle is stopped by an emergency (hazard warning lights)
- to indicate priority for police, fire brigade, ambulance etc. (emergency lights)

Currently, the main marking lights are as follows:

- position/parking lights (to mark the presence, the position and the width of the vehicle—both from the front and the rear)
- side marker lights (to mark the presence and the length of the vehicle)

The back-up, or reversing, lights fall in a separate category. They help the driver to see while reversing (see above) but they also signal to other road users behind the car that it is reversing.

There are, in principle, analogous corresponding requirements for the signal and marking lights to those for the illumination lights. Because of the different purposes, however, there are considerable differences in light distributions.

The main problem with the signaling and marking lights is that the same intensities are used both day and night. It seems self evident that with a difference in general illumination of more than a factor of 1,000, the minimum (and maximum) intensity values should be different in order to maintain corresponding contrasts and visibility. The European regulation leaves this possibility open for turn signals and for stop lights. It allows for a factor of six in maximum and minimum intensity difference between day and night conditions. However, no car manufacturer has taken advantage of this possibility.

Emergency lights for police, fire engines and ambulances illustrate the problem well. The regulation in Europe prescribes a blue flashing light, which is perceived to be too intense at night and too weak during bright sunshine. When brake lights can be made with two levels of intensity (one for clear atmosphere and one more intensive for fog) why cannot the other signaling and marking lights have two intensities, one for the nighttime and one for the daytime?

The signaling and marking lights have much softer gradients of their light distribution than do the illumination lights. Therefore they are not as sensitive to aiming. Nevertheless, measurements in actual traffic indicate that the values in traffic are often much lower than the values in the requirements. For example, Cobb (1990) has shown that in Great Britain, about 50 percent of the rear lights did not pass the minimum intensity requirements even after cleaning. Rear lights of trucks and trailers were especially deficient.

The main reasons for the failure to pass the regulation seem to be general aging, such as bulb failure, blackening of the bulb, dirt, dust, cracked lenses, poor reflectors, and condensation. Rear fog lights are a special problem. They are often left on even after the fog is gone. One way to avoid that specific problem could be automatically to switch them off each time the engine is stopped.

All lights on bicycles, are in reality, marking lights. Even the headlight is so weak that it cannot really be used to improve visibility if the speed is not unusually low. Bicycles are very often seen in night traffic without functioning lights. The energy to the lamps is often supplied by generators, which increase the pedal resistance by about 25 percent. To avoid the increased resistance cyclists often turn off their generators. But the main cause is that the quality of bicycle lighting is very low. It is sensitive to many factors and not very reliable. Therefore, it is especially important to equip bicycles with retroreflectors (see below).

Together these influences work to reduce the intensities of the signaling and marking lights. This, of course, reduces the contrast between the signal light and its background, which in turn will influence the visibility of the signal.

Special vehicle markings that function like lights but are not lights, are retroreflective materials and, to some extent, fluorescent materials. Retroreflective materials are used for improved visibility at night, and they require illumination from headlights. Fluorescent materials are used for improved visibility at lower levels of daylight. Fluorescent materials are very seldom used separately on vehicles. They are often used in combination with retroreflective materials, in order to improve visibility both at lower levels of daylight and during nighttime. Rear markings of heavy and long vehicles and of slow-moving vehicles are good examples.

Retroreflective markings are often used separately to mark vehicles in the same way as position and side lights. Therefore, they are also often combined with or placed at about the same place as position and parking lights. In many countries, the license plate is retroreflective. From the perspective of the driver, retroreflectors function like marking lights when they are illuminated by headlights. But they are never as effective as lights and they are more sensitive to dirt and abrasion than lights, because the light has to pass twice through a retroreflector.

As indicated above, retroreflectors are especially important and effective for bicycles because of unreliable lighting systems on bicycles. Bicycles should always have front, rear, and side reflectors mounted. Tire and spoke-mounted side reflectors have proved quite effective.

In summary, the situation concerning signaling and marking lights is at least as bad as it is for illumination lights. The real traffic conditions are much worse than those designated in regulations. Their intensities and contrasts are considerably lower than intended and, consequently, their visibility is reduced.

3.1.3 Conspicuity lighting

The only current lighting system that is designed to enhance conspicuity is daytime running lights (DRLs). Specifically, DRLs are intended to enhance the conspicuity of the vehicle in daylight conditions. By conspicuity we mean here the capacity of the light to attract attention of other road users, normally in their peripheral field of vision.

The European regulations state that the intensity of the DRLs should be between 400 and 800 cd, with a light distribution corresponding to that of the turn signals. They are not designed to illuminate something. In North America, a wider range of intensities is accepted.

There are five main issues associated with DRLs. One is the effectiveness from a safety point of view. Is it worth the extra energy needed and the quicker burning out of lamps? Most studies indicate that DRLs improve safety, Also, it appears that the farther from the equator, the greater the effect (CIE, 1993; Elvik, 1996; Koornstra et al., 1997). Another issue is the fact that in most designs, signaling and marking lights are also turned on together with the DRLs. This may create a masking effect on signal lights, such as brake lights and turn signals.

A third issue is that a conspicuity light should preferably have a very wide angular visibility to increase angular conspicuity at intersections and for unprotected road users. Some of the lights used as DRLs today do not have a wide, angular, light distribution.

The fourth issue is that as long as DRLs are used but are not compulsory, the vehicles without DRLs are probably less visible than if no vehicles had DRLs. The fifth issue is that in some countries the user resistance against DRLs is quite strong: Many people do not understand why vehicles should have their lights on during daylight.

One thing that is often forgotten in the discussion about DRLs is that they are intended as much for the unprotected road users as for other drivers. In Sweden, where DRLs are compulsory, pedestrians and bicyclists often report that when they intend to cross a street, they see the DRLs of an approaching vehicle in their visual periphery before they detect the vehicle itself. A Swedish accident analysis (Andersson and Nilsson, 1981) also reports that the largest effect of DRLs is a reduction of accidents involving unprotected road users.

3.1.4 Interior lighting

Interior lighting includes the following:

- lighting of the instrument panel controls and displays that relate to either the driving task or other tasks such as controlling the radio, recorder, climate, telephone, and various ITS (intelligent transportation system) functions.
- lighting for reading (e.g., maps)
- lighting for getting in and out of the vehicle
- lighting for getting around in the vehicle (e.g. finding door handles, seat belts, window controls, ash trays)
- lighting of the storage compartments (mainly the glove compartment and the trunk)

The instruments are usually fairly well illuminated and not too difficult to read and understand. The lighting intensity of the instruments is normally variable to suit both day and night conditions. Some of the instrument and control functions and symbols are also standardized, although not in form and location. On the other hand, illumination of the controls and the rest of the interior of cars is generally not standardized. It is therefore very important to illuminate the various handles and controls in such a way that they may be easy to find and to identify at low levels of ambient illumination or in complete darkness.

In many vehicle makes and models, it is difficult to see in dark conditions how to get in and get out of the vehicle. The problem is to see where to put the feet and what available space there is. There is a need for better lighting of the floor and the doorsteps of the vehicle, of the ground just outside the doors, and in the trunk.

3.2 The importance of visual performance in actual traffic

This section will compare visual capabilities of old road users with the present illumination systems. The goal is to find if there are traffic situations or illumination designs in which the needs of old drivers are overlooked, or not sufficiently taken into account.

There are at least three ways to approach this task:

- Start with the accident situations typical for aged road users and attempt to find the variables that could be important from the vehicle lighting point of view.
- Start with the most differentiating age-related visual parameters and attempt to see which traffic situations and which vehicle lighting parameters could be critical.
- Start with a driver model and try to find which age-related visual characteristics are likely to be important, and from there which vehicle lighting parameters are likely to be relevant.

We will try to apply all three methods. Let us start with the accident approach. As was concluded earlier, the self-regulating behavior of old road users makes the accident-statistics approach somewhat biased. In the beginning of this report, studies were cited which showed that the increase in accident rate in nighttime traffic for old drivers in the United States is not as steep as for young drivers. In Germany the old drivers show a limited increase, and in Sweden the old drivers have practically no increase in the accident rate at night compared with that during the day. These somewhat surprising results should be expected from self-regulating behavior.

Earlier in the report, where our knowledge about vision and visual performance was analyzed, it was made quite clear that old drivers have considerably reduced capacity in many visual variables that should be relevant for night traffic.

Why is it that the effects of visual degradation do not show more clearly in the accident statistics? Davison (1978) in his early review of vision and road safety proposed a number of reasons that we will use and expand upon:

- Vision is only one of many factors that influence driving performance and accident involvement. It is therefore difficult to establish a high correlation between one visual parameter and accidents. The highest accident rates in almost all situations are found for young drivers. At the same time, young drivers have the best visual performance. This, of course, reduces the overall correlation between visual performance and accidents. It is, therefore, natural that the highest correlations between visual performance and accidents are found among old drivers.
- There is probably large individual variation in the extent to which these visual parameters are used by drivers. Some rely very much on vision while driving. Others are much less active visually.
- Many of the simple, traditional visual parameters are probably not of much relevance in driving. Static visual acuity in good lighting conditions is probably an irrelevant measure for a driver in night traffic.

- Very few drivers have very poor vision. The reasons are that young drivers have good vision and that old drivers with reduced visual capacity avoid driving, especially in conditions where their visual degradation is a handicap. Consequently, the population of drivers is a selection of those who have relatively good vision. That reduces the likelihood of obtaining high correlations.
- Drivers with bad vision who still drive (normally old drivers, who do not want to lose their mobility) compensate for their visual handicap by driving more carefully, more cautiously, more slowly.
- The criterion most often examined is accidents, because they have an indisputable validity. However, the reliability of accidents as a criterion is questionable because of the low numbers of accidents that studies of vision normally work with. The alternative is to work more with driver performance criteria. That is probably better, but the disadvantage is that the validity of performance criteria may always be questioned.
- Finally, many studies of vision and road safety are unfortunately not of the best quality, especially the earlier studies. Sometimes the design of the study is poor, sometimes the sampling of the subjects is biased, and sometimes the control of potentially confounding variables is inadequate.

This is the situation we are facing when we want to use the accident approach. When we want to find relations between vision and even more detailed accident situations (such as single-vehicle nighttime accidents) in order to establish the importance of some vehicle-illumination systems, our situation is even worse. The probability that we will find any clear correlation is very small. What we may find are potential problem areas. To get further we normally have to use one of the other two approaches: visual performance analysis for old road users or driver model analysis.

The analysis of age-related visual performance should preferably be used for situations that we have a priori reasons to believe are difficult for old road users. Such situations may be selected on the basis of either accident analysis or subjective reports from old road users. They could also be selected on the basis of which of the performance measures deteriorate most with age, or which visual variables differentiate best between old and other road users. Once the relevant situations are chosen, it remains to be determined which lighting variables may facilitate the driving task for old road users.

The third approach—a driver model—is not as simple as it may sound. There are a number of different driver models, or rather there are a number of driver models that focus on different parts of driving. Therefore, they look very different from each other, although they may have many second-order variables in common. None of the existing models is considered outstanding and applicable to all driver situations. There is no model for driver behavior in nighttime traffic.

The most frequent application of driver models in recent years has been in the area of Intelligent Transportation Systems (ITS). This is to be expected because in this area it is seldom possible to perform field tests; the equipment exists only on the drawing board. In this research area a modification of a model originally designed for industry operators by Rasmussen has become the most commonly used driver model (Janssen, 1979). The model is based on three levels of action: knowledge based or strategic (trip planning), rule based or tactical (in traffic maneuvers), and skill based or operational (car handling). However it does not seem to fit our purposes so well because most of the vehicle lighting functions belong to the middle (maneuvering) level.

The oldest driver performance model and, at the same time, the only perceptually based model is from 1938 (Gibson and Crooks, 1938). It has an appealing simplicity, because instead of dividing the driving task into a number of subtasks (as most often models do), it summarizes all of the driver's actions into in two major tasks. Intuitively, this seems to resemble more what we as drivers really do. We do not add together a number of subestimations to reach our decision. Driving seems to drivers to be one fairly simple task. Gibson and Crook's model states that what the driver does is to lay out in front of him or herself a safe area of driving and a minimum stopping distance. The stopping distance seems to be of no interest in this connection since it is not lighting related. The safe area of driving, however, is of the utmost importance from the vehicle lighting point of view. In night traffic, the size of this area will be influenced by how well the vehicle illumination system manages to illuminate the area in front of the vehicle. It will also be influenced by how well the signaling and marking systems are perceived and understood. If nothing else, the vehicle illumination analysis of this legendary driver model shows how important lighting variables are from the point of view of driver behavior.

Another model that has also been used in ITS research is more task oriented (Rumar, 1986). The basic outline is given in Figure 3. This model has many features in common with Rasmussen's model, but the maneuvering level is divided into several tasks: negotiating the road with stationary obstacles, interacting with other moving road users, compliance with rules, signals and signs, and handling of other tasks in the car (radio, climate controls, etc.). This model makes it clearer that driving is a self-paced task, in which the speed is the dependent variable. This is something that is especially applicable to old drivers. We have therefore chosen this model in our analysis of which visual parameters of the aging road user might be important for vehicle lighting characteristics.

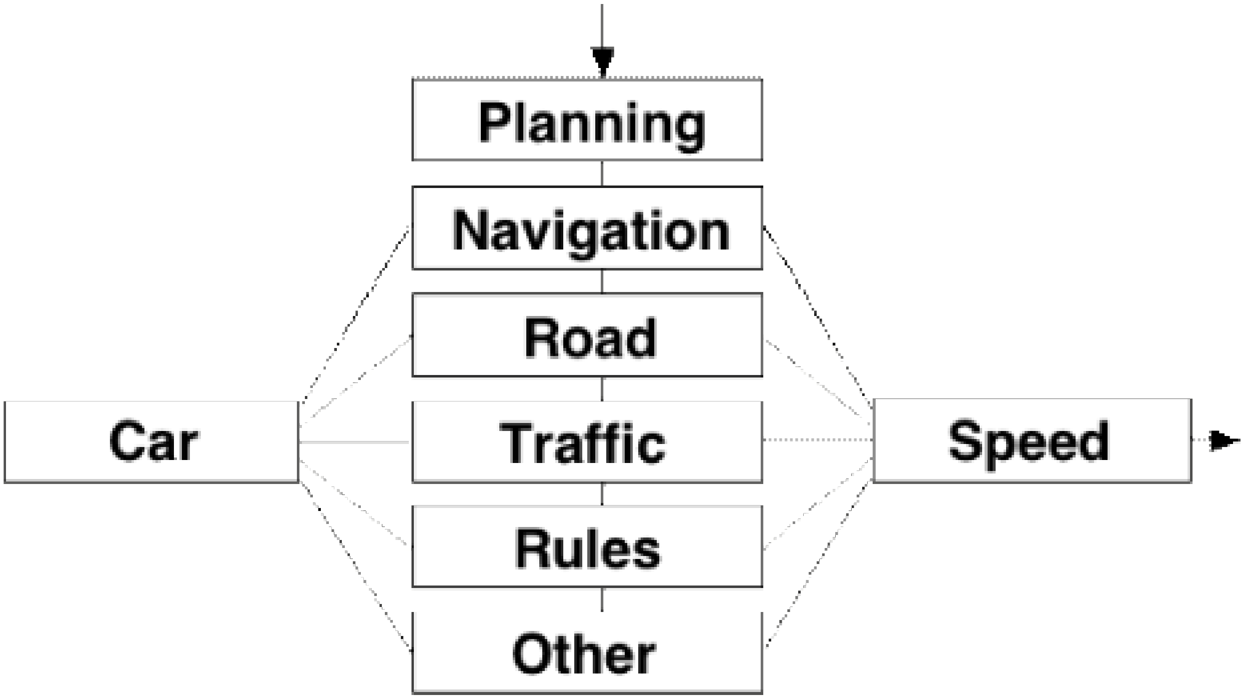

Figure 3. A driver task model used to analyze which age-related characteristics might be relevant for design of vehicle lighting (Rumar, 1986).

3.3 Age and vehicle illumination

Vehicle illumination systems are only used during nighttime. Therefore we limit this analysis to nighttime only.

3.3.1 Accident approach

The first approach is based on accident data. No study that directly tries to relate vehicle illumination variables to accidents for old road users has been found. How about nighttime accidents of old road users? To begin with, it is known that old road users avoid nighttime travel because they find it difficult and dangerous. Another finding is that old drivers tend to drive slower than young drivers in situations they find difficult. Nighttime driving is such a situation. Therefore, any accident data will be biased in the sense that any age effects would most probably be stronger if all old users were traveling at night to the same extent, and at the same speeds, as young road users.

In the beginning of the report we referred to nighttime and daytime accident rates for various ages. In the United States it was found that, despite the age-related modification of travel patterns mentioned above, the nighttime accident rate increases for old drivers. In Germany the increase was smaller than in the U.S., and in Sweden there was no increase.

Furthermore, the types of accidents that old drivers are involved in differ somewhat from day to night. Multi-vehicle crashes, in which the vehicle of the old driver is hit from the side are typical both for day and night. However, old drivers are underinvolved in single-vehicle crashes during the day, but overinvolved in single-vehicle crashes at night.

Among pedestrians, the avoidance of travel at night is so strong that it becomes obvious also in accident statistics: old pedestrians are overinvolved in accidents during the day and under-involved in accidents during the night.

It is difficult to draw any conclusions from the limited studies of old road users and nighttime accidents. The information is not specific enough to be able to identify any specific visual or illumination parameters. The fact that old drivers are overinvolved in angular and turn accidents both during day and night does not help us. The main reason is probably more cognitive than visual. Some conclusions may be drawn from the fact that old drivers are overinvolved in single-vehicle accidents at night but not during the day. Those results support Owens' hypothesis that for old drivers at night both detection and guidance functions are impaired.

Among young drivers, high speed and inadequate vehicle handling is one of the main factors in single-vehicle accidents. However, among old drivers neither of these factors could explain the situation. The most probable alternative is that the visibility of the road for the old driver is inadequate. There are of course various countermeasures for this. One is improved marking of the road, the road markings, and the signs. The other possibility is improved vehicle illumination of the road and its marking systems. A combination of both countermeasures is, of course, also possible.

Improved nighttime marking of the road for old drivers has been studied and suggested by Staplin et al. (1989), Lee et al. (1991), and Pietrucha et al. (1995). Their conclusions are that typical old drivers require the contrast between the road and the road markings to be two times the value that young drivers require. Furthermore, old drivers with poor visual performance may need as much as twenty times higher contrast. This need for higher contrast is especially pronounced during poor environmental conditions, such as those involving wet road surfaces. There does not seem to be any interaction between age and the size of the road markings. The visual performance of old road users was improved most by increases in retroreflectance. In wet conditions, increased retroreflectance can only be reached by raising the markings above the wet surface. That conclusion also points in the direction of reflectorized side-post delineators, which proved very effective for two reasons: They are comparatively insensitive to water, and they offer large projected retroreflective surfaces.

However, Kallberg (1993) in his study of the safety effect of side-post delineators obtained somewhat surprising results. He found that on roads with low geometrical quality the sign-post delineators resulted in increased nighttime speeds. As a consequence, nighttime traffic accidents increased by about 50 percent! On roads with high geometric quality, there were no marked effects on either speed or accidents during nighttime. Sign-post delineators seem to increase comfort and subjective safety, which can lead to an increase in speed. A question that was not studied is whether the effect is the same for old drivers, who are more careful, drive more slowly and really need improved guidance.

Another strategy to improve visual guidance in night driving would be to improve the visibility of the road itself. Concrete roads are more visible than asphalt roads when using either vehicle lighting or street lighting. Again, however, wet roads present the most critical conditions. And for wet roads, the critical thing is not the brightness, but the roughness of the surface. Rough road surfaces always leave some parts of the surface above the water and these parts reflect light back to the driver. However, even better than rough surfaces are draining surfaces in which water is let through the surface and does not stay on top of it. Tests show that on roads with draining asphalt the reflectance of vehicle illumination back towards the eyes of the driver is increased, and the reflectance towards the oncoming driver (glare) reduced.

From a road-guidance point of view, the vehicle illumination systems should be wide to illuminate curves and road markings. The latest proposal for a harmonized low beam pattern as presented by the GTB working group seems to reflect these requirements. Whether the improvements are far reaching enough is difficult to estimate. Another vehicle illumination approach would be to make the illumination more intelligent so that it can follow curves and avoid glaring oncoming drivers (e.g., Rumar, 1997).

Age effects on nighttime visibility and legibility of traffic signs have been studied by Sivak, Olson, and Pastalan (1981), Staplin et al. (1989), Olson (1990), and Mace et al. (1994). As expected, it is well established that old drivers detect and read signs at shorter distances than do young drivers. The increase in contrast needed for old drivers seems to be in the region of two to three times. The conspicuity and legibility problem may be solved by better illumination, or by using signs that are larger or have higher retroreflectivity.

As has been mentioned several times earlier, traffic sign conspicuity and legibility may seem like purely visual tasks. But, there are several indications that this is not the case, at least for old drivers. Their focus of attention is clearly on the road. We know that they have problems dividing their attention to several tasks. Furthermore, there are no visual parameters that predict sign-reading performance.

The question here is whether vehicle illumination systems might play a role. The effect of increasing the illumination towards the sign is the same as using more efficient retroreflective materials. The drawback is that the increased-illumination alternative only works without oncoming road users. With oncoming road users, the increased illumination will also add to the glare for the oncoming road users. Thus, the advantage for the driver of the vehicle will be accompanied by a disadvantage for the oncoming driver.

Another interesting accident characteristic that has been pointed out above is the fact that drivers show a marked increase in hitting unprotected road users at night, and that this increase is stronger the higher the age of the driver (up to retirement age). Again, the visual impairment of the old driver is the most probable explanation for this effect. There are two types of countermeasures available. One is improved marking of pedestrians and bicyclists, the other one is improved vehicle illumination to facilitate detection and identification of the unprotected road users. It is, of course, possible to combine both approaches.

Improved marking of pedestrians has been studied by many researchers, including Johansson et al. (1963) and Luoma et al. (1996). Common to all studies is that they have found that retroreflective markings increase contrasts and thereby increase driver detection distance to pedestrians. Luoma et al. (1996) studied the recognition distance as a function of where the retroreflective material is placed on the pedestrian. They found that the best identification of the pedestrian was obtained when the material was placed at the joints or the limbs. For young drivers, there was no difference in recognition between joint and limb positioning. But for old drivers the positioning at the joints resulted in earlier recognition of the pedestrians. With the increasing use of retroreflective materials along our roads, it becomes more important to recognize what the target really is (e.g., a pedestrian vs. a mailbox).

To match or improve on the visibility provided by retroreflective materials by using better vehicle illumination is possible but difficult. As usual, the main problem is the low beams. To reach the goal we would have to increase illumination considerably without really increasing the glare substantially. Consequently, alternative illumination systems that may offer increased illumination without any increase in glare, such as polarized headlights and UV-headlights are being considered. (However, UV-headlights require fluorescent materials on the targets in order to function satisfactorily.)

Another approach would be to make the vehicle illumination more intelligent so that it can illuminate the signs and the pedestrians without glaring the oncoming drivers. This, however, requires a rather complicated system, which is unlikely to reach large-scale production in the near future (Rumar, 1997). An intermediate solution may be to increase the number of beams from two to, maybe, eight (AFS, 1996). Then, depending on the driving condition, one beam may be directed more towards traffic signs.

A simple way to maintain the beam distributions of low beams, as well as of fog and curve lights, would be to keep the headlights clean. In some countries (e.g., Sweden), headlight cleaners are common and effective. In poor weather conditions (the use of road salt and studded tires), a driver may lose 50 percent of the illumination during a one-hour drive (Rumar, 1974). Sivak, Flannagan, Traube, Kojima, and Aoki (1997) showed that after driving about ten days during the winter in the northern part of the United States, the reduction could be around 25 percent with a similar increase in glare.

There are many disadvantages with trying to solve the conspicuity and visibility problems by means of modifying vehicle illumination. However, there are also advantages. One advantage with vehicle illumination is that it is easier to keep it in fairly good condition. Road signs and especially road markings get dirty, worn, and degraded for other reasons (e.g., UV radiation). Furthermore, the light has to pass the dirt layers twice on signs but only once on headlights. Many signs are just put up and left for many years without any restoration. However, the signs on the main roads are normally kept in good condition.

3.3.2 Vision approach

The second approach for identifying countermeasures involves starting with those visual parameters that differentiate between old and young persons. The next step involves using these differentiating parameters to either identify critical vehicle illumination variables or analyze in which traffic situations those visual parameters might be important, and then identify relevant vehicle-illumination variables.

There are a large number of visual parameters that differentiate between old and young persons. As indicated above, we will concentrate on those visual parameters that are of relevance for vision at low levels of illumination.

The first such visual parameter is the reduction of the pupil diameter, which limits the light reaching the retina. However, it also reduces the effects of the impaired optical characteristics of the old human eye. Another parameter is dark adaptation. A third parameter is the effect of night myopia on visual acuity. A fourth parameter is contrast sensitivity. A fifth parameter involves glare sensitivity and glare recovery. Finally, some studies indicate that distance and speed estimation may also be problems for old road users in night traffic. These parameters will be discussed in more detail in the following paragraphs.

Furthermore, there are some parameters that have visual and cognitive aspects: peripheral vision, divided attention, visual search, and useful field of view. Finally, we should consider the hypothesis that visual impairment at night among old persons influences both recognition and guidance. Visual impairment among young and middle-aged persons affects primarily recognition and not guidance.

The reduced pupil diameter has for long been thought to be a major variable in the reduced visual performance of old road users in night traffic. And it is, of course, true that it reduces the light reaching the retina. However, new evidence seems to indicate that increasing the retinal diameter could lead to negative consequences, such as increased glare sensitivity and impaired visual acuity. A possible vehicle illumination countermeasure could, of course, be increased illumination intensity, if glare can be controlled.

The reduction of sensitivity reached after dark adaptation seems to be of secondary importance. Most nighttime driving is carried out at mesopic illumination levels. Some driving in well-illuminated areas is even carried out at photopic adaptation levels. On the other hand, scotopic adaptation levels are reached in only very limited cases. However, for pedestrians and, to some extent, bicyclists the scotopic adaptation levels are probably of relevance. Vehicle illumination from opposing vehicles may destroy adequate adaptation.

Night myopia is a problem that has large variations between individuals. A lack of correction leads to a blur of the retinal image. But most old persons get more and more farsighted (presbyopic) over the age of about 45 (Weale, 1963). The obvious countermeasure for night myopia is adequate visual correction. However, such corrections are rarely carried out, mainly due to lack of adequate testing equipment. There is no obvious way to counteract night myopia by means of vehicle illumination systems.

The impaired contrast sensitivity for old persons at lower levels of illumination is one of the main and most important age effects. Low contrast targets do differentiate better between young and old subjects than do high contrast targets. Contrast sensitivity has been shown to correlate well with many traffic-related variables, such as subjectively reported, age-dependent visual problems and legibility of road signs. Contrast sensitivity also seems to be a good measure to diagnose the existence of various age-dependent pathological conditions of the eye, such as cataracts. In a simulated study of daytime driving performance, Wood and Troutbeck (1995) found that the old subjects performed significantly worse in reaction times to peripheral stimuli and in a reversing task. Low contrast sensitivity and useful field of view were the best visual predictors of driving performance.

Bhise et al. (1989) analyzed the effects of low contrast sensitivity of old persons using a visibility model (DETECT). In general, the predicted detection distances for old drivers were substantially shorter than those of young drivers. Furthermore, adding age-related contrast sensitivity data resulted in more detrimental effects than introducing age-related glare sensitivity data. What was not tested, however, was whether increased illumination (and proportionally increased glare) would have an overall positive effect.

An obvious countermeasure for the reduced contrast sensitivity of old road users would be an increase in the contrasts of the relevant targets. This brings us back to what has already been said about increased use of high-performance retroreflective materials and increased vehicle illumination. In many of the studies referred to earlier, it has been stated that tests of visual contrast differentiate between drivers who perform well in traffic situations and those who do not. In other words, contrast sensitivity could be used to differentiate a good visual environment from a poor visual environment, and to separate a good vehicle-illumination system from a poor vehicle-illumination system.

Glare sensitivity and glare recovery are two variables that may not be as closely related as their names might imply. Disability glare is probably mostly a consequence of light spread in the ocular media. Various age-related pathological conditions may have significant influence on disability glare. Glare recovery, on the other hand, is probably more a chemical and neural effect in the retina. Retinal diseases probably play an important role here. Old road users complain about both effects, and both effects work to reduce target contrast and driver comfort. Glare problems are in fact one of the main reasons why old drivers avoid driving at night.

One possible countermeasure to overcome the age-related visual problems of glare sensitivity and glare recovery would involve a vehicle illumination system with considerably reduced glare intensities. This brings us back to what was said above concerning alternative vehicle illumination systems (e.g., polarized, and UV) or an intelligent vehicle illumination system. Less efficient, but still worthwhile, countermeasures would involve limiting the glare increases due to vehicle loading, headlight misaiming, dirt on headlights, and vehicle dynamics.

Another alternative for dealing with glare problems would involve increasing the contrast of the relevant targets by using high-performance retroreflective materials. Other possibilities include drugs, filters, or other optical devices that would reduce the glare problems of old drivers without creating new problems.

Distance and speed estimation in road-traffic situations are difficult tasks during daylight conditions. Such estimations are even more difficult at nighttime when gradients, background cues, and peripheral stimuli are often missing. Poor ambient conditions make it difficult to use the natural cues normally present in the visual field. Relative motion and motion parallax are only two of a number of missing cues.

It is hard for everybody to make speed and distance estimations at night. There is no evidence that these estimations are more difficult for old than for young persons. There are, however, indications that old road users rely more on distance estimation than do young persons. If that is the case, then they are probably more handicapped at nighttime because distance estimation is so difficult. It is not obvious how vehicle-illumination systems could reduce those problems. One possibility would be contour illumination (or contour marking with retroreflective materials).

Reduction in target contrast, decrease in ambient illumination, and increase in peripheral eccentricity all cause problems with eye movements. Although this applies to everyone, we have reasons to believe that old persons are especially influenced. Old subjects are likely to also have problems with pursuit eye movements over a speed of about 10 degrees per second compared with about 30 degrees per second for young subjects. One way to counteract these types of problems would, again, be to mark road users and obstacles better, either with light or with retroreflective material. The role of vehicle illumination systems would then be to illuminate the retroreflective materials. Consequently, a wider beam pattern would be good for old drivers.

The driving task is, to some extent, a visual search task. Studies have shown that the smaller the contrast, the more complex the background, and the larger the uncertainty about the position of the target, the harder it is for old subjects to perform well in visual search tasks. The background in night traffic is not complex, even if it is sometimes very difficult to interpret. But the contrasts of the relevant targets are often low, and the uncertainty about the position of the target is great.

Studies of the useful field of view (UFOV) indicate that visual search becomes more difficult for old subjects as the cognitive load increases. There are no established methods for measuring cognitive or perceptual load caused by poor visibility conditions. However, such load on old drivers is likely to be substantial, especially if, as postulated, visual guidance is impaired for old drivers. In such cases, improved visual guidance would help old drivers also to detect unprotected road users and other obstacles along the way. Here again, we have an argument for increased use of high-performance retroreflective materials for road delineation and for potential obstacles, as well as for improved vehicle illumination in these directions.

3.3.3 Driver-model approach

The driver model for this analysis considers eight tasks that the driver has to carry out. Let us see in which of these night-traffic situations age-critical conditions of relevance for vehicle-illumination systems may appear. The eight tasks are:

1. strategic choice of travel mode, travel route, time of departure, etc.
2. navigation—finding and following the route chosen
3. following the road—keeping on the road and avoiding obstacles on the road
4. interaction—interacting with other road users
5. rules— following the traffic rules and restrictions created by signs, markings, and signals
6. non-driving tasks (e.g., climate, radio, telephone, ITS, etc.)
7. maneuvering the car (e.g., steering, braking, accelerating, switching between beams, using turn signals, etc.) For a beginner this is a large, demanding and difficult task. For the experienced driver it is a routine and often automatic task
8. speed adjustment—influencing the attentional demand and work load

The old road user—whether he is a driver, a bicyclist or a pedestrian—will behave differently from the young or middle-aged road user in respect to the first task involving strategic decisions. As has been stated repeatedly, the old driver will often avoid nighttime driving by choosing another time for departure, choosing another mode, or not making the trip at all.

The second task—finding the chosen route—will also be performed differently by drivers of different ages. The old driver will have chosen a familiar route, which he knows he can find. If he has to drive in an unfamiliar area he will probably have some difficulty. He will at least reduce the speed to get more time to navigate. Signs that are easier to read, vehicle-illumination systems that illuminate the signs better, and signs positioned at the appropriate location will, of course, be helpful.

The third task—following the road—is the same task for old and young drivers. But, the visual, perceptual, and cognitive demands will be much greater on the old driver. Slowing down will help older drivers in most cases, because keeping on the road is the last task a driver gives up. The problem is that following the road might use so much capacity that the old driver will have problems handling other more intermittent tasks, such as detecting unprotected road users. Again, better marking of the road and of the obstacles, and better vehicle illumination systems would facilitate the task.

The fourth task—interacting with other road users—is in general, the main problem area for the old road user. It is in these, often complicated situations, which demand divided attention and quick decisions, that the primarily cognitive limitations among old persons show up. This task is, certainly, not easier at night, but it is difficult to imagine how vehicle-illumination systems could influence or facilitate this task. Furthermore, irritating and masking glare from other vehicles would make this task even more difficult.

The fifth task—following rules, signs, and signals—is more of a problem for the young road users than for the old ones. Studies indicate that old drivers follow rules to an extent that might, actually, not be safe. Their rigidity and inflexibility could sometimes be a disadvantage. Old drivers prefer signal-regulated crossings to any other type of crossing, because the rule is so simple and the necessary estimations, judgments, and decisions are very limited. Furthermore, the time pressure is marginal. Another problem develops if the old driver did not see a sign, a marking or a signal (due to cognitive load or visual impairment) and, therefore, appears to violate the regulation. Better sign materials and better vehicle illumination might help here. A further problem occurs if an old driver first stops at a stop sign, but then continues without noticing other traffic. An improved conspicuity of vehicles would likely be beneficial (see conspicuity below).

The sixth and seventh tasks—in-car tasks other than driving and car handling—do not depend on vehicle illumination, but on interior lighting (see that section below).

The eighth task—speed adjustment—is dependent on all the other tasks. However, if we assume them to be unchanged, except for visibility, speed adjustment will depend on how well drivers estimate that they can see. That is, the better the visibility and the better the visual guidance, the higher the speed. Thus, the first important question is whether speed will increase more than visibility allows. In other words, would increased visibility lead to an increase or decrease in safety? There are some studies that indicate that safety will decrease with improved visual guidance (e.g., the side-post delineator study by Kallberg, 1993). The second important question is whether old drivers behave differently from other drivers. The fact that they reduce their speed more at night might point in that direction, but could also indicate that they do so because their visual capacity and their lower visual guidance is poorer.

Because safety is our primary concern, this is a critical question. If improved visibility impairs safety and impaired visibility improves safety, a desirable strategy would have to be to impair visibility as far as possible. Then daylight would be the most dangerous situation. The problem in the case of the side-post delineators could be that the *perceived* improvement of visibility is larger than the real improvement. Maybe the drivers are lured into a false sense of safety. It is possible that side-post delineators make drivers believe that they see the road and targets much better than is really the case. Furthermore, safety is not our only concern. We are also interested in mobility and comfort.

Improved vehicle illumination will improve driver visibility but do so in a general way. The whole traffic scene is improved. Retroreflective side-post delineators only improve road visibility and only the general outline of the road. Side-post delineators do not increase visibility of obstacles or other road users. They do not increase visibility of the road surface. In other words, improved vehicle illumination is probably a good safety measure to improve the speed-adaptation task, at least for old drivers.

3.4 Age and vehicle signaling and marking

Vehicle signaling must work during both day and night. Vehicle marking, on the other hand, is primarily important during nighttime. Therefore, this section includes both day and night conditions.

3.4.1 Accident approach

No studies were uncovered on the role of driver age in accidents in which vehicle signaling and marking is a contributory factor.

3.4.2 Vision approach

Again, no studies were uncovered on the relation of age-related visual performance on vehicle signaling and marking lights. However, the results of the studies on visual and cognitive performance of old persons provide some leads.

Let us start with the signaling lights (turn signals, brake lights, and hazard warning lights). The turn signals are used primarily at intersections but also in lane-changing situations. Normally, the driver does not fixate the turn signals of another car if they are not lighted. Furthermore, the reaction expected by other road users on activated turn signals is not simple. The reaction depends on the situation. The driver has to make an assessment of the total traffic situation before a decision is made about what to do. Generally, turn signals do not trigger automatic reactions.

The flashing of the turn signals is normally very conspicuous. However, in bright sunshine or fog old persons with reduced contrast sensitivity may have difficulties detecting them. Furthermore, from the front they may be masked by lit headlights, and from the rear they may be masked by the rear position lights and the brake lights.

Old persons' diminished perception of the brightness of the signaling and marking lights can lead to decreased color sensitivity. This makes it harder for persons above about 60 to separate colors within the blue/green part of the spectrum. At higher ages, problems within the yellow/red part of the spectrum may also appear.

It is difficult to see how turn signals could be improved to overcome these age-related problems, because the problems are, to such a large extent, cognitive and not visual. However, two levels of intensity (day and night) would certainly help. In fact, a more continuous adaptation of signal intensity to ambient illumination would be the best. Other countermeasures could include separating turn signals better from headlights and rear lights, placing the turn signals higher up on the vehicle (to be more central in the visual field), and using only amber color for turn signals. Finally, turn signals, like all signaling and marking lights, should be kept in good condition (clean, etc.).

The problem with brake lights is almost exclusively visual. The expected reaction is clear-cut. What should be done is very much the same as with turn signals: at least two intensity levels, separation from other lighting functions, central position (CHMSL), and good working condition.

Hazard warning lights should primarily be used on stationary cars, stopped by an emergency. These signals usually appear in the center of the visual field. There is usually no time pressure and the reaction expected is simple—slow down.

The few possible problems with hazard warning lights would be solved if the countermeasures proposed for the turn signals were implemented.

The problems with the various marking lights from the driver's age point of view is intensity. However, in this case having variable intensity does not seem equally important, because the width, the length, and the height of vehicles are sufficiently visible in most daytime conditions. Increased intensity may, however, create new problems, because it is important to have a difference between signaling and marking lights not only in color and position, but also in intensity.

As was indicated earlier, the bicycle lights (both front and rear) are really marking lights. The best ones have light intensity high enough even for old road users. The reliability is, however, really poor, and it should be improved not only from the point of view of the old road users, but for everybody. Another major problem is recognition. Normally, the bicycle lights are just point sources. It is difficult for drivers to identify that an object in front of them is a bicycle and not a side-post delineator or a pedestrian. The same applies, to some extent, for moped and motorcycle rear lights.

A general problem that is probably further enhanced for old drivers is recognition of targets at night. Therefore, identification should not be based on abstract symbols but on a more ecological stimulus. A good example is the retroreflectorized contour marking for trucks. Side-mounted, tire-side, reflex retroreflectors common on bicycles in some countries, provide a circular global impression (a gestalt), which is usually associated with two-wheelers. It should be possible to find an equally striking symbol for two-wheelers seen from the front or the rear. Maybe a vertical line?

In the illumination section, much was said about retroreflective markings. It is not necessary to repeat it here. They are excellent markers, provided that the vehicle illumination is sufficient. Furthermore, they offer good opportunities to create pictures (gestalts) of the vehicle or the pedestrian (Luoma et al., 1996). It has long been thought that luminous intensity of the retroreflector was the only important variable with respect to detection distance. However Sayer et al. (1998) have shown that color is an important factor as well.

3.5 Age and vehicle conspicuity

It does not seem meaningful in this short section to distinguish the accident, visual, and modeling approaches. There are no accident studies related to age. The visual analysis must be based on reduced contrast sensitivity and reduced field of view. The modeling analysis is based on the fact that late detection is the basic driver error (Rumar, 1990).

Considering that old road users often make mistakes and step out or drive out in front of oncoming vehicles, DRLs (daytime running lights) should be made compulsory. An important consideration here is a decrease in conspicuity that vehicles without DRLs might suffer when most vehicles have DRLs. Low beams seem to work fine from a perceptual point of view. They are, however, unnecessarily expensive to run, and, therefore, dedicated daytime running lights or daytime running lights combined with some other existing lighting function are to be preferred. Judging from experiences and public reactions in some countries (e.g., in the U.S.) it will be necessary to have intensive campaigns before such laws are implemented.

The peak intensity of dedicated DRLs in the fifties and sixties was too low (below 100 cd). When low beams were used as daytime running lights, the intensities were acceptable (500-1,000 cd). In the seventies and eighties the peak intensity levels of dedicated DRLs exceeded 200 cd. Currently, the levels preferred are considerably higher (400-7,000 cd). Considering the reduced light sensitivity of old road users, the intensity of the dedicated DRLs should be at least 400 cd.

Old road users have problems in intersections. From that point of view, wide-angle DRLs are preferable. The width of the DRL beam should be at least as wide as the beam of turn signals. DRLs should be positioned near headlights so that appearance (for identification) and distance estimation are not affected.

As was stated earlier, DRLs can mask both front and rear signal lights. At the rear this could be handled by not having rear lights turned on with DRLs. At the front, the distance between DRLs and turn signals should be made sufficient.

3.6 Age and interior vehicle lighting

Again, there is no need to treat separately the three approaches outlined above (accidents, visual, and model). There are no accident studies available. The visual analysis is based mainly on reduced light and contrast sensitivity, and on reduced eye movement performance of old road users. The model analysis falls into one category—other tasks in the vehicle. Here we have to base our analysis, to a large extent, on subjective reactions of old drivers and car occupants.

What is needed from an age point of view concerning the interior lighting are primarily the following:

- better illumination and marking of instruments and especially controls (The main lighting switch is an excellent example of an important control, which seems to be different in almost every car. The control of the windshield wipers is another good example.)
- better illumination for seeing and reading in the car and its compartments
- better illumination for stepping in and out of the car

It is difficult for many old drivers to quickly read the instruments and to identify and find controls. One problem is probably the same as for road signs—low contrast sensitivity. The countermeasure should also be the same—higher contrast and/or larger symbols. Another problem is the accommodation from looking far ahead to fixating close by on the instruments and controls. Instruments could be optically influenced to be perceived far away, but it is difficult to imagine how controls could be handled the same way. Therefore, the countermeasure in this respect must be visual correction.

Another problem for old drivers and car occupants is to find handles and other key points (to insert ignition key, to lock the seat belts, to open the door or the window, to open the trunk or the glove compartment) and other controls that have nothing to do with the primary driving task (e.g., seat controls, light controls, climate controls, child seat connections, ash tray). Here, illuminated markings would be a great improvement. Also some kind of standardization of the form and the position would help. The forms used and the symbols of many are not very legible and understandable.

Finally, old drivers complain about problems of getting in and out of the vehicle. What we can do by means of vehicle lighting is to improve visibility of the floor near the doors, and the ground just outside the door at night. This should not be too difficult and would certainly be appreciated by old car occupants.

4. Proposals for Age-Based Modifications of Vehicle Lighting

Old road users clearly avoid nighttime travel because they experience it as difficult and dangerous. Results from studies of the visual performance of old road users show that this fear is justified. Therefore, nighttime travel would be even more dangerous to old road users than what the current accident statistics indicate if the old road users were participating to the extent that other road users do. Therefore, there are two reasons to improve the nighttime traffic situation for old road users: to increase their mobility, and to improve their safety.

In earlier sections of this report, the approach has mainly been from the visual direction. In this section, the approach will be reversed. We will start with the lighting parameters and try to analyze what could be changed in order to meet better the requirements of old road users. Conclusions on possible lighting modifications will be drawn from the results presented earlier and the discussions carried out on the basis of these results and observations.

In earlier sections, the ambition has been to present the basic facts available that may make it possible to evaluate the vehicle lighting systems from an old road-user point of view. In this chapter proposals for possible improvements especially for old road users will be made. The arguments put forward for some of the suggestions are sometimes quite speculative, but they are made to stimulate discussion and provoke thinking.

The vehicle lighting systems will be treated in the same order as they were earlier: illumination, signaling and marking, conspicuity, and interior lighting.

4.1 Proposals for illumination systems

In section 3.1.1 the problems with present illumination systems were outlined. Section 3.3 discussed the consequences of these problems for old persons together with illumination analyses based on accident statistics of old road users, visual characteristics of the old persons, and driver modeling. The intention here is to present a basis for a discussion of possible changes of vehicle-illumination systems to better suit old road users.

There are, in principle, three main ways to reduce the age-related nighttime visibility problems:

- more extensive use of road lighting
- better vehicle illumination systems
- better marking of visual tasks

We will not deal with road lighting in this discussion. We know it is effective, but it is also expensive and energy consuming. Given that there are no special city beams for lighted road areas, the glare control of the vehicle illumination system will also influence the visibility on lighted roads. More glare from vehicle illumination means less visibility on lighted roads. This is another argument for having several beams for different purposes (see below).

Better marking of the visual tasks, primarily by means of retroreflective materials, has many advantages. It is relatively inexpensive and visually very effective because such materials increase the most critical variable—contrast—by a factor of several hundred. However, it has one main disadvantage. Retroreflective materials only improve visibility and legibility of the target on which they are placed. There are always targets or obstacles on which it is very difficult, if not impossible, to place retroreflective materials (e.g., wild animals, dropped cargo, a fallen tree). This may lead to relatively decreased visibility of the unmarked targets and to higher speeds because of the general impression of very good visibility (Kallberg, 1993).

The illumination of primary interest here is provided by the low beams. It has been argued earlier that the design of the low beam involves an impossible dilemma between visibility and glare. This dilemma is even more pronounced for old drivers because they need more light to see, and they are more sensitive to glare. Old drivers really need better vehicle-illumination systems.

Better illumination systems is a sweeping statement. It contains mainly two competing variables, with which lighting engineers have been struggling as long as we have had electrical vehicle-illumination systems: more intensive illumination of the scene in front of the driver, and less glare towards other road users. Each of these two parts may be divided into subvariables.

The illumination needed to increase visibility of the road and the traffic scene may be divided into the following ten parts:

- more light straight ahead (high quality straight roads, high speed, preparation time)
- more light to the sides of the road ahead, beyond about 100 m (e.g., road geometry, targets and obstacles along and beside the road, lower quality roads and speeds)
- more light to the sides of the road close to the vehicle, up to about 100 m (e.g., guidance, position on the road, intersections, narrow curves, pedestrians intending to cross)
- more light on the road itself, beyond about 50 m (e.g., other road users, parked cars, road markings, potholes, bumps, large and small objects)
- less foreground light on the road close to the car, up to about 25 m (to reduce adaptation level and self glare, to create a more uniform road luminance pattern and not to attract eye fixations)
- more light higher up on both sides of the road, but especially on the right hand side beyond about 25 m (road signs)
- the asymmetry of the beam distribution to make it possible to increase illumination more on the near side of the road (more frequent visual targets and less frequent opposing drivers)
- more light below the horizon and up to about 100 m (to penetrate haze, fog, snow, etc.)
- more light rearwards, up to about 25 m (to facilitate visibility rearwards when backing)

The glare part of illumination systems may be divided into the following five subvariables:

- less glare against the opposing driver and other road users when driving on comparatively straight and flat roads (design glare)
- less glare against opposing drivers and other road users when driving on roads with lower geometrical standards (horizontal and vertical curves, transient glare)
- less reflected glare against oncoming drivers when driving on wet roads with high specular reflection (reflected glare)
- less glare into the rear view mirrors of vehicles ahead (mirror glare)
- less backscattering of vehicle illumination when driving in haze, fog, or snow (self-glare) (This is not really glare in its traditional sense. But the veiling effect works in a way in the same manner – masking low contrast targets.)

In-between the visibility and glare variables is a variable of its own: the sharpness of the vertical intensity gradient from high-intensity illumination for good visibility to low-intensity illumination for reduced glare.

The main nighttime visibility problems for old road users of relevance to illumination systems are as follows:

- reduced sensitivity to light
- reduced contrast sensitivity
- increased glare sensitivity
- increased glare recovery time
- reduced useful field of view
- reduced visual guidance along the road
- reduced detection and legibility distances to road signs
- reduced detection and recognition of obstacles on the road

From a simple comparison between the preferred changes of the illumination and the visibility variables it is obvious that old road users would benefit from all of these illumination and glare improvements. However, so would everybody else. In this respect the answer to the question, stated earlier, of whether countermeasures that are good for old road would be good for everybody else, is a resounding “Yes!” However, from this it does not follow that any improvement will give the same benefits for old and young road users. Because the visual performance of old road users is lower than that of young road users, young road users may benefit more from one modification (e.g., higher light intensity straight ahead), while old road users may benefit more from another modification (e.g., more light along the road close to the car). But all age groups will benefit, and no age group will suffer as a consequence of a modification carried out to help primarily the old road user.

Most of these variables (except for sharpness of the vertical gradient, less foreground light, and possibly the asymmetry of the beam distribution) are not controversial. The controversy comes in when the visibility illumination and the glare must be weighted against each other.

Sharpness of the vertical gradient, however, is a very special variable in the design of low beams. A sharp gradient is a consequence of trying to get as much light as possible below the horizontal (i.e., below the cutoff) for good visibility, and as little light as possible above the horizontal to reduce glare for the opposing driver. A strict application of this would result in a very sharp cutoff; such a cutoff would require a precision of aiming that is not possible because of changes in road geometry. Without very accurate dynamic aiming the sharp cutoff will sometimes dip down and thus seriously reduce the visibility for the driver. Sometimes it will swing up, and thus seriously increase glare and thereby decrease the visibility for the opposing driver.

The continuous vertical motion of the cutoff on uneven roads is, furthermore, annoying to the driver and might negatively affect eye-fixation patterns (by moving eye-fixations closer to the vehicle). Graf and Krebs (1976) have shown that daylight fixation is normally a couple of hundred meters ahead while none of the headlight patterns studied exceeded half that distance. They furthermore found that the fixation pattern with a U.S.-type soft cutoff was slightly farther away from the vehicle than with a European-type sharp cutoff.

A very sharp cutoff between visibility illumination and glare limitation would be good if all roads were straight and flat, or if we always could dynamically direct the light in the direction of the main targets and away from the eyes of other road users. But, due to the circumstances above, neither of these requirements holds. Therefore, in the dynamic, real-life traffic situation, it is preferable to have a softer cutoff, in order to avoid severe transient glare and in order to avoid corresponding transient visibility reductions. This approach, however, means that with present low-beam technology we have to accept increased design glare if we want to reach increased illumination far away and high up.

Another consequence of a sharp cutoff is that the visibility below the cutoff is good while visibility above the cutoff is poor. On the other hand, with a soft cutoff, visibility changes gradually. The glare follows an analogous pattern. With a very sharp cutoff the opposing driver is either severely glared or not glared at all. With a soft cutoff the opposing driver is always more-or-less glared. There seems to be a tendency that drivers subjectively prefer to have much light close to the car (foreground illumination). However, the feeling of comfort with high foreground illumination is probably false, because studies have shown that much foreground illumination is negative from the visibility point of view. A sharp cutoff does not necessarily lead to more light close to the car. But because of the contrast effect, beam patterns with a sharp cutoff are generally perceived as having a high level of foreground illumination.

On the other hand, the sharp cutoff, with its high ratio vertically between two close-by illumination points, has the advantage of being easy to aim visually. However, as was pointed out above, the sharp cutoff requires accurate aiming. The soft cutoff does not need the same aiming accuracy because it is not as sensitive. There are many ways to specify where the cutoff is positioned in a gradient. Most researchers agree that the second derivative of the logarithm of the illumination yields the best technical description of where the cutoff is perceived to be positioned. There are also several ways to describe the sharpness of the cutoff, with all giving about the same results. The European cutoff is, in general, about twice as sharp as the traditional U.S. cutoff, with corresponding differences in aiming accuracy (Alferdinck, 1996; Sivak, Flannagan, Chandra, and Gellatly, 1992). But, recent developments in the U.S. concerning visually aimable headlamps have substantially reduced the difference in the sharpness of the cutoff between European and U.S. headlamps.

Most studies indicate that foreground illumination should be limited. Furthermore there is no technical problem to do so because the angular distance of the foreground to the primary visibility areas is relatively large. There is a belief that old drivers feel more comfortable with high levels of foreground illumination. There are, however, no studies to support this hypothesis.

The need for increased illumination on the near side of the road, away from oncoming drivers, is not controversial by itself. However, there is an interaction between the sharpness of the cutoff and the nature of the asymmetry: With a sharp cutoff it is easier to make a more asymmetric beam pattern.

Which of all these improvements should be given priority from the point of view of the old driver? We have to ask that question because the amount of light available is limited. (That in itself is an indication of one of the advantages of high-intensity discharge (HID) lamps as compared with halogen lamps: HID lamps offer approximately twice as much light and several times as long life at the same energy consumption.)

Based on all of the above arguments, the following is a reasonable priority ranking:

Priority I

- more light to the sides of the road ahead, beyond about 100 m
- more light to the sides of the road, up to about 100 m
- more lights on the road itself, beyond about 50 m
- increased lateral asymmetry of the beam pattern
- less glare against oncoming drivers (design glare)
- reduced vertical gradient

Priority II

- more light higher up on both sides of the road, especially beyond about 25 m
- more light straight ahead
- less glare against oncoming drivers (on-the-road glare)

Priority III

- less foreground light
- less reflected light against oncoming drivers when driving on wet roads
- less glare via rearview mirrors

Priority IV

- more light below the horizontal, up to about 100 m (to penetrate fog, etc.)
- less light that could be backscattered in fog, haze, etc.

Priority V

- more light rearwards up to about 25 m

The priority rankings for young drivers would be similar. The main differences are that for young drivers, the highest priority would be for more light straight ahead, followed by more light to the sides of the road up to about 100 m in front of the vehicle. Furthermore, for young drivers, all of the glare variables would have one step lower priority than for the old drivers.

So what should be done about current lighting? The first thing to do should be to make sure that the values given in the regulations and on new cars are also valid in actual traffic. That means that headlights should be kept clean and clear. One solution would be compulsory headlight cleaning. A more advanced approach would involve having a sensor in the headlamp that automatically reacts and starts a cleaning process, or cleans the headlights when the windshields are cleaned, or warns when the headlamp lens or reflector is not clear due to dirt, scratches, haze, condensed water, ice, etc. Such a sensing device could also react to light sources not working. A leveling device could be automatic, and it could include a sensing and warning function to indicate when it was not working properly. The voltage to the light sources could easily be controlled and adjusted automatically. The general aging of illumination systems (including all of the mentioned variables) should be regularly inspected. Old drivers should welcome all these improvements. But their needs would still not be fully met.

As has been discussed earlier, there are only two possibilities for resolving the remaining problems. A different type of vehicle-illumination system that can offer increased seeing illumination without increasing the glare. Such systems are polarized headlights (Johansson and Rumar, 1970) and to some extent UV headlights (Rumar et al., 1989). Another alternative is to have several beams, which may be combined in a flexible way, or to make the vehicle illumination systems adaptable to the situation (see e.g., Rumar, 1997).

Any major modifications to the present headlight systems must be carefully evaluated. Present knowledge about old driver vision is not good enough to make concrete proposals concerning specific values of specific points in the light distributions. The most critical points in the light distribution lay close to the cutoff. For each one of these points, careful weighting must be made of the advantages and disadvantages of changes in visibility and glare.

Alferdinck (1996) performed a literature study of glare that would be acceptable from a disability and discomfort point of view. He recommended a maximum of 1,370 cd at 13.2 V. This is not a major change from the current situation. This value is approximately twice the present ECE value, about the same as the present U.S. level, and approximately 50 percent higher than the recent GTB proposal (Moore, 1997). It seems reasonable to assume that the increase in illumination that would be possible by an increase in glare limits of such a magnitude would be proportionally about the same.

Old road users seem to complain more about the intense glare than about the poor visibility. But, in experimental studies, lack of visibility illumination is a larger problem than is glare. It is, however, important to realize that while the disturbing glare is very obvious and always present (with opposing vehicles), the impaired visibility is very difficult to estimate, and is obvious only in some situations. Therefore, subjective complaints should not be given too much weight in the choice between focus on visibility or glare.

The conclusion from this discussion is that the old driver’s visibility at night would benefit from increasing the visibility illumination of present low beams, even if that would result in increased glare levels. Compared with the present European low beams, this is what is suggested in the present proposal for a harmonized beam pattern (Moore, 1997). However, compared with the present U.S. low beams, the proposed glare levels would be lowered. (Nevertheless, illumination in the visibility zones close to the cutoff would, in general, be increased.)

4.1.1 Effects on visibility

First, let us analyze the relations between the two main lighting parameters of relevance to vehicle-illumination systems (illumination intensity for visibility, and glare intensity against oncoming drivers) and visual performance. Figures 4 and 5 outline what such relations may look like. Although we are not sure what form the visual performance curve for the old persons may look like, it probably lies in the shaded areas of the two figures. The main purpose of Figure 4 is to show that, although an increased illumination is good for all ages, old drivers are likely to benefit more than young drivers. The same goes for reducing glare (Figure 5). It is good for both groups, but old drivers are likely to benefit more.

The visibility improvements expected as an effect of the proposed vehicle-illumination modifications described above are difficult to specify. However, if more radical solutions were chosen (e.g., polarized headlights) the visibility conditions for old drivers (and young) in difficult situations would increase by at least a factor of two. If, on the other hand, only the proposed modifications of the present vehicle illumination system were carried out, the visibility improvements would be in the range of 10 to 20 percent for old as well as young drivers. If all the proposed improvements of marking by means of retroreflective materials would be implemented, then the visibility of the marked targets would be improved by more than a factor of three. If, finally, all the possible improvements were made (visual correction, draining road surfaces, contour marking on all vehicles, etc.), the visibility conditions for old drivers would be further improved in special situations.

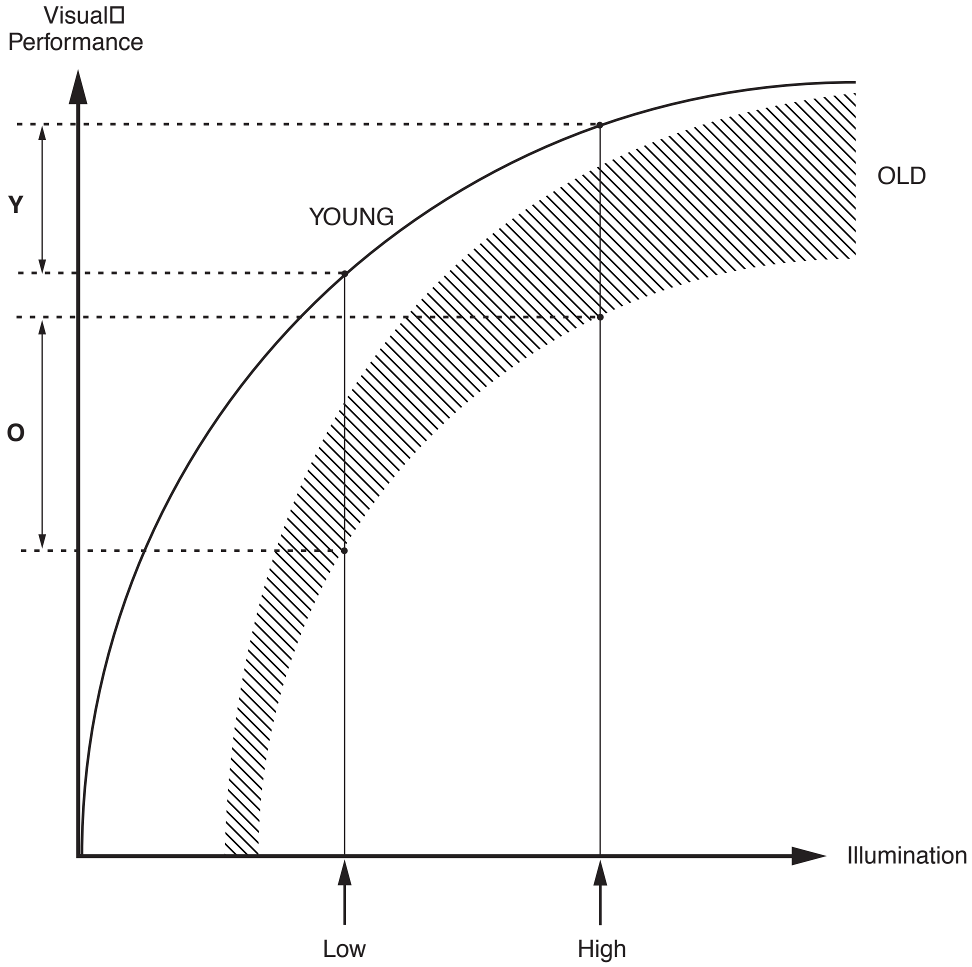

Figure 4. A hypothetical relationship between headlight illumination and visual performance for young and old drivers. While all drivers benefit from an increase in headlight illumination, old drivers benefit more than do young drivers.

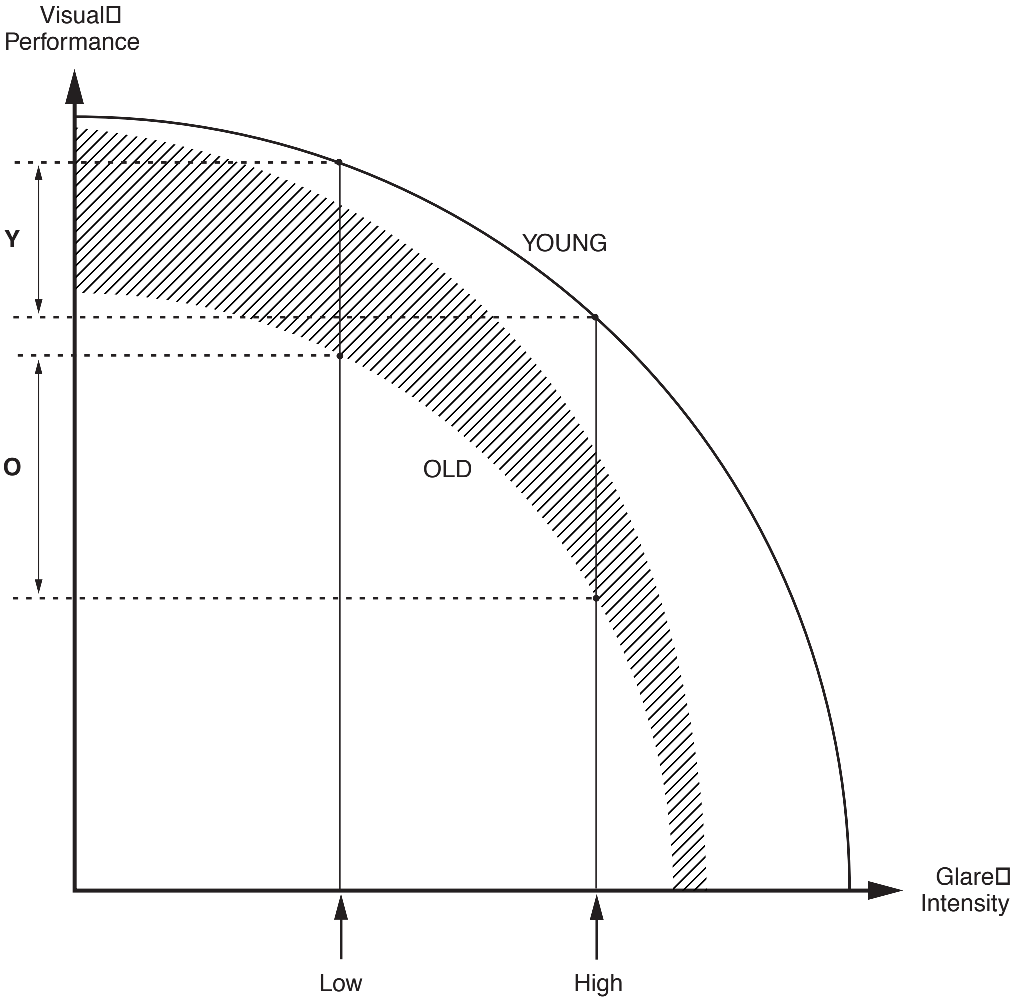

Figure 5. A hypothetical relationship between glare intensity and visual performance for young and old drivers. While all drivers suffer from an increase in glare intensity, old drivers suffer more than do young drivers.

High beams, spot lights, curve lights, fog lights, and back-up lights have not been mentioned in this section. The reason is that they do not constitute any major problem. High beams and spot lights can be increased to the legal maximum intensities. From a visibility point of view, it would probably be an advantage to widen the beam pattern instead of necessarily providing more light down the road as far as possible. As a result, the road geometry would be better perceived, and road users or animals intending to cross the road would be more visible. The inverse-square law of light reduces the visual efficiency of light the farther away from the vehicle an object is. The fog lights, curve lights, and back-up lights are not intended to offer visibility far ahead at high speeds.

The back-up lights normally show very poor performance. They appear to be designed primarily to signal to drivers behind that the car is in reverse, and they do not offer good visibility to the reversing driver. Especially old drivers and professional drivers complain about this.

There is no evidence that the effects of the above-discussed changes in vehicle illumination systems geared towards old drivers would have any negative effects on any other groups of road users. In other words, the curves in Figures 5 and 6 would never cross. Furthermore, young drivers would probably benefit from even more illumination (and could tolerate more glare). Nevertheless, the situation proposed would still be better than the current situation. The unprotected road users would receive more glare and be more disturbed. But they would be more visible and have a greater probability of survival in night traffic.

An important issue is the effect that improved vehicle illumination systems would have on safety if old road users were to increase their nighttime road travel. An alternative is to designate some major roads as special high visibility roads for old drivers, and keep the other roads as they are. That solution would be very difficult to implement because it would require that we decide where old persons should go and where they should not go. That makes it clear that selecting "old" routes is not a viable alternative. Judging from the behavior of old persons in nighttime traffic, the increased risk would probably be limited because of their self-regulation and because the glare would be at least as annoying as before. (Glare was proven to be one of the main reasons for abstaining from driving at night.)

For the unprotected road users, the increased glare would probably result in even greater avoidance of night travel, despite the fact that their visibility would be improved.

4.2 Proposals for signaling and marking systems

In section 3.1.2 the problems with the present vehicle signaling and marking lights are outlined. In section 3.4 the age-related visual problems of relevance for vehicle signaling and marking lights are analyzed. There are no direct studies concerning old persons and no wide-spread complaints from old road users concerning vehicle signaling and marking lights.

For the above-discussed forward visibility there were alternative solutions for modifying the traditional vehicle illumination systems. However, for vehicle signaling there appears to be only one broad category of alternatives—ITS. By making the signals electronic it is possible to move them from the signaling vehicle into the interior of the other adjacent vehicles. However, we will not treat this alternative here.

Potential variables to be modified in vehicle signaling and marking lights, in order to help old road users, are as follows:

- signal intensity
- signal luminance or area
- separation in space between various signaling and marking functions
- positioning (in the visual field) of the signaling and marking lights
- angular (geometric) visibility of signals and markings
- separation of colors for different signaling and marking functions

- separation of positions of various signaling and marking lights
- flashing rates (for turn signals, hazard warning lights, and emergency warning lights)
- new signaling patterns

According to the studies cited above, the main age related visibility problems of relevance to vehicle signaling and marking lights are:

- reduced sensitivity to light
- reduced contrast sensitivity
- increased glare sensitivity
- reduced useful field of view
- reduced sensitivity in the peripheral field
- reduced temporal resolution (critical flicker fusion-CFF)
- reduced color sensitivity
- reduced speed and accuracy of eye movements

Young persons have one main problem with vehicle signal lights: They do not always see or detect them early enough. Old persons have probably two types of problems with vehicle signal lights: visibility problems and cognitive problems. By cognitive problems we mean difficulties in integrating the message from the signals in the decision process, difficulties separating relevant from irrelevant signals, and difficulties detecting the signals in the periphery of the eye. Some of the cognitive problems may be reduced by lighting measures, but others may not.

The vehicle signal lights are not fully ecological or natural; their meaning is acquired through exposure to traffic situations. However, over the years they have developed an almost ecological content for everybody used to road traffic. For example, when brake lights flash in front of a driver, he brakes almost without thinking about it. Many current proposals involve changing the brake lights. Suggestions include introduction of temporal, spatial, or color changes to increase the detection probability or reduce lamp rise time; and increased informational value of the brake light (e.g., signaling the intensity of braking). This is something we probably should be very careful with from an old-road-user point of view. We know that the old road user relies strongly on established habits and reactions, and that he has problems in establishing new automatic reactions. Therefore, new signal patterns must not deviate much from the basic patterns of existing signals.

Historically, turns were indicated by arm signals. It is therefore logical that the first turn signals consisted of a small red arm being unfolded. Later came sequentially presented lights and the current flashing turn signals, which are much more conspicuous. There have been several special solutions such as the small centrally mounted roof indicator on Volvos in the sixties. It had a 360-degree visibility. But it was difficult to determine from a distance which side was flashing.

Traditionally, signaling and marking lamps have used tungsten filament bulbs (as have vehicle illumination lamps). During the nineties new light sources have been developed (LED, neon), which could be well suited for signaling and marking lights. They have several advantages over filament bulbs (e.g., fast rise time, long life, free form, and low energy consumption). However, the regulations are still based on the traditional technology.

There are many differences between signaling and marking lights. One important difference is the fact that signal lights indicate that something has happened or will happen. As a consequence, the driver will have to make a decision about how to react to the new information. Signaling lights should therefore always attract attention, be detected and decoded. This applies to both day and night. If possible, a driver should be made aware of what the next move of other road users around him will be. That way he will be prepared and better handle the coming events. Good signal lights can give him that preparation. Old drivers probably need that preparation time more than young drivers.

The marking lights have two different purposes. First, they are primarily intended to mark a situation: the position, the width, the length, the height, or the type of vehicle. Marking lights also facilitate the estimation of how far away a vehicle is, which course it is taking etc. Second, marking lights facilitate the detection and recognition of the vehicle. No immediate action is necessary unless the detection is made very late (e.g., when coming over a hill crest). Marking lights are beneficial primarily during the nighttime. A good illustration of the difference is that marking lights in many situations can be replaced by retroreflective materials with acceptable results. On the other hand, retroreflective materials can never replace signal lights. Old drivers seem to need stronger markings of vehicles than young drivers.

There are many differences between the European and U.S. regulations. However, during the past few years, a harmonization working group within GTB has done a good job in creating ”windows of opportunity” between the two regulations that will make it possible to produce and sell a vehicle fulfilling both sets of regulations without changing the signaling and marking lights.

The first proposal for improvements of signaling and marking lights to help old road users is to have two levels of intensity—one for daylight and one for nighttime. The ECE regulations leave that opportunity open by allowing a factor of six between day and night intensities for stop lights and turn signals. Unfortunately, this possibility to make dual-intensity signaling lights has not been used. The dual intensity would make it possible to optimize the intensities instead of the present compromise intensity, which must be not too weak during the day but not too bright during the night.

The second proposal is to ensure that the lights fulfill the regulations also out on the road, in real traffic. This implies more reliable performance in general—including lifetime of the light source. The new technologies (LED, neon) may be of great assistance here. They may also reduce the problems associated with corrosion, haze, heat distortion, cracks, etc. The main strategy must be to build lights with higher quality requirements.

Let us now return to the lighting variables of relevance (such as intensity and luminance) and match that list with the list of visual problems of old persons. The natural question is which of the lighting variables should be modified to better suit old road users.

Most studies seem to support the idea that vehicle marking and signaling lights normally may be treated as point sources. That is to say, the total amount of light from the lamp that reaches the eyes of observer determines the performance. However, the luminance of the light emitting surface plays a role as well, especially at shorter distances. The higher the luminance, the more discomfort, or annoyance, is perceived.

As discussed above, signal lights must attract attention, and thus will inevitably be somewhat annoying. On the other hand, marking lights should not attract attention in the same way. They must not be annoying, especially because they are constantly in the visual field while signal lights are only there for short intervals.

There appear to be four types of problems with vehicle signaling and marking lights for old persons. One problem is the decreased sensitivity in the peripheral visual field. Another problem is decreased contrast sensitivity. Thus, signal lights need to be made more conspicuous, especially during the daytime. Another problem is impaired eye movements, especially long eye movements. The final problem is that we need more space to separate the various functions from each other, and there is not much space available in the front and the rear of modern vehicles.

One way out of this dilemma might be to retain current intensities of marking and signaling lights, but to make signaling lights smaller, thereby creating a stronger signal value. Furthermore, this would offer considerably greater freedom in positioning the smaller signal lights wherever they would be most visible. The possibility of increased discomfort glare could be reduced if the signal lights had two intensity levels (a lower one at nighttime and a higher one at daytime).

A central position in the visual field is the best position for signal lights. The successful example set by the center high-mounted stop lights (CHMSL) illustrates that better than any theoretical analysis. Therefore as a potential improvement, it is proposed to make signal lights smaller and position them higher. This should lead to greater attention value. Emergency lights are already high up to insure a high level of conspicuity.

The marking lights could, thus, remain as they are, but improved spacing and better separation of function would make them function better. Furthermore, there might be a danger in moving them. Their present positions are now so well established that distance and speed estimation might be endangered if they were moved. Contour marking of vehicles has been used with retroreflective materials and proved efficient. It could be possible to do the same thing with modern lighting technology. That would certainly help old road users to estimate the distance to oncoming vehicles.

Although old persons have a reduced capacity for temporal resolution of light pulses, the frequencies used for turn signals, hazard warning lights, and emergency warning lights are so low that no change is needed.

Old persons have slightly reduced color sensitivity. However, the colors used in vehicle lighting (white, yellow, and red) are different enough not to cause any additional problems for old persons. Maybe the time has come to harmonize the color boundaries of amber/yellow signals. Furthermore, it would likely be beneficial if all turn signals were yellow (including the rear ones in the United States if they are functionally separated from other rear lights).

There is some concern that using turn signal lamps with clear lenses and colored filament bulbs might make it more difficult to decide in bright, sunny conditions whether the signal is on or not (Sivak, Flannagan, Traube, and Kojima, 1998). This is not a specific age problem. However, due to the reduced contrast sensitivity of old persons they may suffer more than others from such masking effects.

Lenses may also be black or the same color as the body of the car. Such solutions will probably be favorable because they increase the contrast. Studies have also shown that reaction times to such signals are somewhat faster compared to the traditional design (Sivak and Flannagan, 1991; Chandra et al., 1993).

Finally, some comments should be made concerning new signal patterns of brake lights. The goals of such patterns are to improve detection of the onset of braking and the awareness of high deceleration.

Detection of braking onset is proposed to be improved by the use of light sources with a faster rise time, by turning on brake lights when the foot is lifted from the accelerator, and by making brake lights flash. Awareness of strong deceleration could be assisted by turning on more brake lights or larger area of brake lights, changing the color of the light, or flashing at a higher rate.

As was indicated above, we should be careful not to make major changes in well established signal patterns because old drivers may have special difficulties in reprogramming their reactions. On the other hand, it should be possible to improve a signal system that has clear deficiencies. But new ideas should be carefully tested, primarily by using old drivers.

4.2.1 Effects on visibility

The proposed improvement made concerning vehicle signaling and marking lights include the following modifications:

- Two level intensity (day and night)
- Better quality, more reliable, longer life, cleaner, etc.
- Smaller, high-positioned yellow turn signals (after careful testing)
- Contour marking of vehicles
- Improved brake-light signaling pattern after careful testing with old persons

Marking lights would remain virtually unchanged. However, since the turn signals would be separated, there would be more space for marking lights, and thus the probability of confusion should be reduced.

It is not possible to estimate the effects of the proposed changes on conspicuity, visibility, recognition, and reaction time. However, considering the substantial effects of CHMSL on conspicuity, reaction time, and accidents, there are reasons to be optimistic. The overall effect could be considerable, and especially so for old road users.

4.3 Proposals for conspicuity systems

Contrary to the other vehicle lighting systems, the conspicuity lights (daytime running lights-DRLs) are intended only for daytime use. The intention is that they should attract attention to the approaching vehicle seen in the periphery of the visual field. Because the purpose is to stimulate the periphery of the eyes, the old road users (with decreased useful field of view) are likely to benefit more from DRLs than would young road users.

The lighting variables of interest are:

- illumination intensity
- light distribution
- color of light
- position of lights
- wiring with other light sources
- automatic or manual
- mandatory or voluntary
- alternative DRLs

The light-intensity range presently accepted—from minimum 400 cd in Europe to maximum 7,000 cd in the United States—is quite wide. However, different DRLs are designed for different applications. The 400 cd refers mainly to lower daylight levels and long twilight periods in northern Europe, while the 7,000 cd more refers to high daylight levels in the Southern United States.

The light distribution of DRLs should be considered from two points of view: long distance straight ahead, and short distance wide. DRLs should work on straight roads for opposing drivers, for road users ahead intending to change direction, and drivers or other road users on an intersecting road waiting to cross the road. Consequently, the central light distribution near H-V is of primary interest. But DRLs should also work in urban areas and on curvy roads, and in those situations a wider distribution is needed. A simple way of finding a suitable light distribution is to compare DRLs with another light function with corresponding requirements, such as turn signals. Thus, DRLs should have light distributions corresponding to turn signals. That is the situation in the ECE regulation.

The color of DRLs is white if we use low beams. Studies indicate that yellow (which is the only other acceptable color for the front) might have a higher attention value. However, it seems logical to keep the yellow turn signals and the side markers, and to have DRLs be white. That way the risk of DRLs masking the turn signals would also be reduced.

The positioning of the DRLs should be considered from the point of view of distance estimation. Old road users tend to rely more on distance judgment than other road users. Studies have shown that a standard headlight distance of the DRLs would facilitate veridical distance judgments. Consequently, DRLs should be positioned roughly at the same distance from each other as the headlights.

To reduce the risk of masking rear signal lights, and also for energy conservation, the DRLs should be lit separately without involving other lighting functions. To avoid the situation that drivers continue to drive into darkness with only DRLs, the illumination of the instrument panel should not be on until the main lighting switch is turned on.

DRLs should be automatic, especially from the point of view of old road users. As soon as the engine is on, DRLs should be on as well. It would be even better if the DRLs came on only when the car was moving. This brings us to an important question concerning whether DRLs should be mandatory or voluntary. It appears that mandatory DRLs would be the most effective solution for old drivers, pedestrians, and bicyclists.

The possible use of vehicle lighting functions other than low beams needs more research. The problem is that for the two purposes of DRLs (long distance ahead, and wide short-distance illumination) two very different light distribution characteristics are needed—high central intensity and wide angle distribution. The existing vehicle lighting functions that could fulfill those two requirements (in addition to low beams) are fog lights and maybe curve lights. It is, of course, possible to modify or combine several lighting functions (e.g., more powerful front position lights or high beams combined with more powerful position lights).

4.3.1 Effects on conspicuity

To help old road users in detecting oncoming or intersecting vehicles, the proposals for conspicuity lights (DRLs) are as follows:

- wide light distribution
- white color
- no other vehicle lights lit together with DRL
- two lamps positioned like the headlights
- automatic switching on and off
- mandatory for cars, motorcycles, trucks, buses, and heavy equipment

Again it is difficult to predict the magnitude of conspicuity improvement that could be expected as a consequence of these proposals. On the one hand, evidence is available that daylight collisions will be reduced for those vehicles equipped with DRLs (Elvik, 1996; Koornstra, 1997). The reduction of daylight collisions is likely to be considerable—10 to 15 percent. Swedish data indicate that even more favorable results are reached for pedestrians and bicyclists. On the other hand, those vehicles not equipped with DRLs will suffer in conspicuity in a vehicle population where a substantial proportion of the vehicles are DRL-equipped. Furthermore, specific vehicle categories already having DRLs (e.g., motorcycles) will suffer a comparative loss in their enhanced conspicuity, if everybody else would have them. But DRLs will increase safety as a whole.

4.4 Proposals for interior lighting

There are no regulations concerning interior lighting of vehicles. Therefore, it is not surprising to note that the variation of interior lighting among cars is very large, probably larger than for any other type of vehicle lighting. This variation applies to both the quantity and the quality of the lighting. Furthermore, it also applies to the way the interior lighting is controlled (i.e., the switches). The groups that suffer most from less-than-optimal interior lighting are the old drivers and the old car occupants.

One of the reasons for this apparent lack of interest in the interior tasks of the driver and the other car occupants at night is probably technical. It is complicated to have a large number of cables to and from light sources and contacts. A new technology – distributive lighting – should reduce the technical problems. However, the main reason for poor interior lighting is a lack of commercial pressure. There are no demands from the government, journalists, or the public. Consequently, interior lighting is frequently forgotten. The old persons who suffer most have so far constituted a very weak pressure group. This might change in the future, as their numbers will increase.

The lighting areas of interest here are as follows:

- lighting of instruments
- lighting of controls
- lighting for reading
- lighting for getting around in the vehicle
- lighting of storage compartments
- lighting for stepping in and out of the vehicle

The lighting of instruments is normally well handled with a regulator that changes the level of illumination. However, the symbols tend to be designed for daylight and are often not clear or big enough for nighttime conditions. Warning lamps and telltales are sufficiently visible at night, but not so in broad daylight when the contrast tends to be too low (especially for the old drivers). As was recommended for exterior marking and signaling lights, interior warning lights should have two levels as well (day/night).

Lighting of controls is generally poorer than that of instrument illumination. Even very important controls (such as the main lighting switch, the defroster, and the fog lights) are often inadequately lighted and sometimes not lighted at all. Other less important controls (such as radio and climate controls) should still be illuminated because searching for them distracts attention from more important tasks.

Although the driver should not be reading while driving, other occupants may want to do so and sometimes need to do so (e.g., reading maps). The reading lights have improved considerably during the last few years. However, there is still room for improvement. Reading in poor illumination is a typical situation where old persons are considerably handicapped. Light should be better focused on the reading areas, in order to increase illumination and to prevent stray light from disturbing the driver.

Anybody entering the driver's seat of an unfamiliar vehicle at night knows that the first problem is to find the keyhole to get the engine working and to get some light. Where is the light switch? Other problems are finding the main controls (see above) and finding and attaching the seat belt. When trying to get out of the same vehicle, the first problem is to find the door handles. Normally none of these fairly important locations are lighted or illuminated. Again old vehicle occupants suffer here the most.

Old persons also complain about how difficult it is to get in and out of the vehicle. These complaints are, to a large degree, more physical (e.g., low seats, narrow foot space, and low roof), but at night the visibility conditions are also a frequent problem. The door threshold, the foot space, the roof border, and the ground outside the door are not illuminated. Consequently, old persons stumble, fall, hit their heads, or step into pools of water or on icy patches often.

Finally, the illumination of the storage compartments in vehicles (glove compartment, trunk, and door compartment) are sometimes lacking, and often are inefficient. There is normally no safety problem associated with that, but it is very inconvenient. And again, it is the old person who suffers most from this lighting deficiency.

4.4.1 Effects of improved interior lighting

Of all lighting improvements proposed to help the old road users, the largest noticeable effects would probably be with interior lighting. The reason for this substantial improvement is not that the proposals have been unusually good but because the present interior lighting generally is so poor. It is not possible to quantify the magnitude of improvement. But one thing is certain: old persons would really appreciate them. It should be possible to make this issue a matter of commercial interest and commercial competition, now that the numbers of old vehicle buyers are increasing.

5. Conclusions

This section will summarize and estimate the total effects of the proposals made. The main focus is on safety. However other aspects such as mobility, comfort, costs, technical feasibility, practical problems, and social participation must also be weighed. Most proposals have both advantages and disadvantages. The weighing of these factors against each other is often very difficult. In some cases, the questions raised are really not lighting questions but political questions.

5.1 Safety

There are three basic questions that must be analyzed:

- If the lighting improvements proposed are so successful that they would lead to an increased number of old drivers, cyclists, and pedestrians on the road at nighttime, would that be a desirable result?
- If the lighting improvements proposed are successful and lead to improved visibility conditions for old road users in night traffic, will that visibility improvement also lead to improved safety, or will the visibility improvements lead to increased speed and constant, or even lowered safety?
- Will tomorrow's old road users have the same characteristics and behavior as today's old road users? This question is important because if there will be a new and different old driver population, we cannot predict what will happen from the results obtained today.

It is not until these three questions have been answered that we may try to analyze what positive and negative safety effects the lighting improvements proposed may have in general and in special situations.

5.1.1 Mobility and safety

Earlier in this report it was shown how old road users' self-regulation keeps accident, injury, and fatality rates lower than what would be expected based on age-related physiological, psychological, and sociological changes. In other words, the old road users compensate for their impairments by avoiding certain situations and by being very careful in other situations that they rightfully feel are very difficult and dangerous for them.

Mobility is an important aspect of quality of life. The fact that old people (drivers, bicyclists, and pedestrians) reduce their mobility results in less participation in everyday life (e.g., visiting their friends and staying until it is dark, going to restaurants or theaters at normal times). Of course, there are also other factors that contribute to this predicament. But, our task is to eliminate the variables that we have control of—the vehicle lighting factors.

In other words, we should not be content with improved safety at the cost of a reduced quality of life. Ideally, safety should be improved or maintained without limiting the mobility of old persons.

Furthermore, Finnish/Swedish data show that preventing old persons from driving a car forces them to use other, often less safe modes of transportation to maintain a minimum of mobility. We might slightly improve automobile safety by limiting old persons' driving, but the total road safety in society would be impaired.

5.1.2 Visibility and safety

There are studies showing that improved visibility may be negative from a safety standpoint. However, it would be a major jump to conclude from such results that improved visibility is dangerous. A careful analysis must be made about what kind of visibility is enhanced, and probably even more important, what kind is not.

To begin with, it has been established that nighttime travel is two to three times as dangerous per mile driven as daytime travel. Studies show that there are many factors contributing to this risk increase, such as alcohol, drugs, presence of young drivers, fatigue, and impaired visibility. Some studies have managed to show that impaired visibility is one of the main factors in especially two types of nighttime accidents: single-vehicle accidents, and collisions between a vehicle and an unprotected road user. Old drivers are overinvolved in both of these types of accidents. This is an indication that improved visibility in itself is probably not dangerous. In fact it would be odd if it was. Then the opposite would also be true—that impaired visibility is good from a safety standpoint.

The data most often referred to concerning visibility and safety comes from a Finnish study, which showed that installing retroreflective side-post delineators along a road could be dangerous, especially on roads with lower geometrical standards (Kallberg, 1993). On roads with higher standards, there was no difference in safety between having or not having side post delineators. What makes this study special is that the road visibility was improved without improving visibility of the road itself or of the obstacles on or along the road. Maybe it is not so peculiar that drivers increased their speed beyond their seeing distance, and thereby created a situation where nighttime safety was impaired instead of improved.

The conclusion from this study should probably be that if visibility of some of the important targets is improved, then also the visibility of the other important targets should be improved. Otherwise, safety might be jeopardized. Improved vehicle-illumination systems enhance visibility in general, while retroreflective materials only enhance the visibility of the marked targets. Therefore, improved vehicle-illumination systems should improve safety in general, although not to the same extent as road lighting does.

Improved vehicle signaling and marking lights facilitate the interaction between road users and thus improve safety in those situations. However, they do not improve safety in general. Vehicle conspicuity lights facilitate detection of vehicles, thereby reducing the probability of a basic road user error—late detection in daylight conditions. Improved vehicle interior lighting probably has marginal effects on safety. However, it may reduce stumbling errors that might be quite serious for old road users. Furthermore, it increases comfort, and decreases distraction and errors that might trigger accidents.

5.1.3 Old road users now and in the future

There is little doubt that the future old generation will be more used to driving cars than the present old generation. This is probably more pronounced in Europe than in the United States. This trend will have the effect that the behavior of future old road users will be different from those of today. They will probably also be healthier, wealthier, and more used to traveling. They will be able to own and drive cars. They will take far greater advantage of their cars than do present old persons. Therefore their general travel and driving behavior will be different.

The visual performance of future old persons will, in all essential aspects, remain unchanged from that of today. The goal of this report is to recommend ways to compensate for the age-related changes in visual performance. That goal should remain unchanged with changes in travel patterns.

5.2 Safety effects of lighting improvements

Because the proposals for vehicle lighting improvements concern very different parts of the vehicle lighting systems, and therefore will have quite different consequences on visibility and safety, they will be treated separately.

5.2.1 Illumination systems

The proposals concerning vehicle illumination are as follows:

- keep the headlights clean and well aimed at all times
- increase illumination intensity ahead to improve visibility, even at the cost of increased glare
- use a soft cutoff in order to make the illumination less sensitive to a variety of influences
- increase the width of the illumination to improve visibility on curves
- increase illumination along the sides of the road and the road markings to improve visual guidance
- increase illumination towards traffic signs and/or improve traffic signs
- decrease foreground illumination
- increase and improve rear-lighting performance for reversing purposes

The basic position is that these modifications should be made on new cars. However, it is also possible to achieve some of these modifications by means of aftermarket auxiliary lights. For example, old drivers could buy spot lights to improve the beam ahead, and curve lights to widen the beam close to the vehicle. But since all suggested improvements will improve the situation for all drivers, they should be built into the vehicle from the start.

It is, as was noted earlier, difficult to make an accurate estimate of the safety effects that the visibility improvements are likely to have. One reason why it is so difficult to make such estimates is that it is difficult to keep all the other variables constant. By way of a comparison, when Europe changed from symmetric to asymmetric low beams in the 1950s, the visibility for most targets and the visibility near the side of the road were improved by approximately 30 percent. Analogously, when Europe changed from incandescent to halogen filament bulbs in the 1970s, the visibility was increased by approximately 10 percent.

The consequences of the improvements suggested here may not be of the same magnitude as those of the asymmetric improvement. But they should be at least of the same magnitude as the halogen improvement, because that did not really change the light distribution. In other words, the visibility improvements are estimated to be 10 to 20 percent, with the lower value for young drivers and the higher value for old drivers.

A visibility improvement of that comparatively limited size will not have any radical effect on nighttime safety. We know from studies of road lighting that visibility improvements of several hundred percent are needed for reaching safety benefits of 30 to 50 percent.

5.2.2 Signaling and marking lights

The proposals include the following:

- two levels of intensity (day and night)
- clean, reliable, and compliant with regulations while in actual use
- smaller, high positioned, and yellow turn signals (after evaluation)
- contour marking of vehicles (improved distance estimation)
- improved brake signaling patterns (after evaluation)

Estimating the effects of these suggested improvements is at least as difficult as estimating the effects of illumination improvements. The only prior relevant experience concerns the center high-mounted stop lights (CHMSLs). Farmer (1996) reviewed earlier studies of safety of CHMSLs and performed a study based on insurance claims. His results are considerably lower than the earlier fleet studies, which most probably overestimated the effects of CHMSLs on rear-end accidents. Based on the results of Farmer (1996), a reduction of 5 percent in relevant rear-end accidents is currently the best estimate of the benefit of CHMSLs in the United States.

Of all marking and signaling lights, rear brake lights may have the most direct accident prevention effects. Therefore it is not possible to extrapolate from the safety effects of special brake lights to safety effects of other signaling and marking lights. However, the proposals concerning light improvements made here influence several functions (including brake lights) and should together reduce vehicle collisions about 5 percent.

5.2.3 Conspicuity lights

The proposals made to facilitate daylight detection of other vehicles by the use of DRLs are as follows:

- Wide beam pattern
- Only two white front lights
- Automatic switching
- Mandatory

Judging from all earlier accident studies of DRLs, daylight accident reduction of 5 to 15 percent can be expected (Elvik, 1996; Koornstra et al., 1997). The higher figure is probably more valid for unprotected road users and for old drivers. The lower figure is probably more valid for other groups.

5.2.4 Interior lighting

The proposals made consist of a number of detailed interior-lighting improvements to help in getting in and out of the vehicle, fastening seat belts, reading instruments, operating controls while driving, and finding one's way in the interior of the vehicle.

These improvements will have marginal effects on road safety. However, they will probably have some beneficial effect in reducing non-driving injuries in and near the vehicle. Furthermore, they will improve comfort and reduce many of the difficulties old persons have when traveling at night.

5.3 Technical aspects

With present modern optical technology (e.g., free-form reflectors, projector lamps, and very accurate lens prisms) it should not be difficult to produce the proposed illumination systems. In fact, a sharp cutoff, which requires very accurate aiming, is probably the most difficult part in designing and producing low-beam headlight systems. The proposal presented here is for a softer cutoff, which is comparatively insensitive to misaim.

More light is required relative to the output of current headlights. That could be solved either by HID light sources (that would also solve the limited lifetime problem) or by several light sources. Efficient cleaning devices already exist. The problem with scratches and haze, especially in plastic lenses, might be a greater difficulty, especially as the proportion of plastic headlights is steadily increasing.

The proposed dual intensity for marking and signaling lights may look simple. However, there may be various technical issues associated with creating more light in small plastic compartments (e.g., heat). Using new light sources would be one approach for these problems. Another problem is to determine when to change from one level to the other. This could be done automatically or by wiring with DRLs.

Light-source lifetime could be increased by using new light sources (LED, neon), which would also eliminate most of the sun masking of signal lights. The reason is that most of the sun masking is created when light is reflected by the reflector. (LED and neon lamps do not need reflectors of the same type as do filament bulbs.)

A new, and not yet evaluated, proposal involves using smaller turn signals. There should be no major technical problem with this proposal. Another suggestion, which has not yet been formally evaluated, is contour marking of the vehicle. That might pose some technical problems. Should it be made by continuous lighted lines or a series of small, lighted points? Where should it be placed to give the right contour impression on the fairly soft body of a modern passenger car? Another proposal consisted of cleaning marking and signaling lights. That might prove difficult. One way of making it easier to implement is to make the outside of the lens flat (without relief) so that dirt does not accumulate in the crevasses. The main dirt problem concerns the rear of vehicles, especially on trucks and trailers.

The proposed conspicuity lights (DRLs) are technically fairly easily implemented, if the low beams are used as DRLs. The intensity may be slightly reduced in order to increase lifetime. But, it is a waste of energy to throw most of the light (and energy) down towards the road where it is of no use for DRLs. Therefore, special and optimized DRLs should be developed that would have (1) better conspicuity characteristics, and (2) less glare and masking effects than the low beams do. The main technical problem is probably where to put them on the car.

The fact that the DRLs should be lit separately, requires some additional wiring. The main switch should be automatic, both to turn them on and to switch from DRLs to low beams when it is getting dark. That should not be a serious technical problem.

None of the proposed modifications to the interior vehicle lighting should create any serious technical problems. Distributed-light technology may facilitate this task.

5.4 Economic aspects

The costs of implementing the proposed improvements are very difficult to estimate and depend on information from the industrial, manufacturing, and commercial sectors. The technical and economic difficulties often go together.

For the illumination systems, the more costly proposals probably constitute an increase of luminous output and a change of the light distribution of the low beams. It is primarily the transition that would be costly. Once the transition is made, the costs should not be much greater than they are today. However, there is one exception. If a new light source would be needed (e.g., HID bulbs), that would make the product considerably more expensive. Products of overall higher quality would also increase costs. On the other hand, higher quality may lead to fewer replacements, which will, in turn, lower the costs. Cleaning systems are available, but adding them to the present designs costs money. Very accurate aiming devices are expensive. One of the advantages of suggesting a softer cutoff is that there would be no need for a very accurate aiming device.

If, instead of modifying the present headlight system, we decide to adopt a new, radical philosophy, the costs would increase. An intelligent, adaptable headlight system (with one dynamic or several static headlights that can be combined in different ways) would be considerably more expensive. Other, more radical, solutions such as polarized headlights may be less expensive than adaptable systems, even including all the filters needed in front of the eyes of the drivers.

The modification of the marking and signaling lights along the lines proposed here will probably be more expensive. Overall improvements in quality, two levels of intensity, smaller turn signals, and a cleaning system may require new materials and new manufacturing principles. Other costly ideas suggested are contour marking (because of the amount of treatment needed). New, more diversified, and dynamic brake-light patterns should not be too costly.

The costs for introducing DRLs would depend on the type of implementation. A low-beam solution would be inexpensive to produce, but somewhat more expensive to run. Dedicated and optimized DRLs would be more expensive to produce, but less expensive to run. The costs for the advanced interior lighting proposed may be considerable. However, interior-lighting improvements may be individualized, and thus should not be made mandatory (contrary to most of the other proposals for vehicle lighting improvements). The old person (and anybody else interested) may order the interior-lighting improvements and pay for them separately.

5.5 Research needs

Several of the proposals made for improvement of vehicle lighting have not been studied sufficiently to be immediately implemented. Therefore, applied research is needed concerning a number of specific issues. There are also several more basic research problems concerning vision and behavior of old persons in traffic that need to be studied.

5.5.1 Basic research

There are several tentative models of driver behavior. They are either very specific (e.g., dealing with overtaking or car following behavior), or very general and rather superficial. But neither the specific nor the general models have been developed or evaluated using old drivers. Therefore, our knowledge concerning driving behavior of old drivers is very limited. Knowledge concerning behavior in night traffic is even more limited. One of the basic questions is how old drivers use speed as the regulating variable.

It has been mentioned in several places in this report that driving is a self-paced task, but that the reductions in speed when the task becomes more difficult do not fully compensate for the increase in task difficulty. Overall risk increases as task difficulty increases. However, this evidence is not based on old drivers. Consequently, we should investigate whether this finding is applicable to old drivers as well.

Another relatively basic question deals with automatic processes. How much of normal driving and night driving is automatic? Is there a large difference between old, middle-aged, and young drivers? How strong is automatic behavior, and what does it take to interfere in automatic processes?

As indicated earlier, old drivers probably rely more on distance judgments than do young drivers. That is an interesting hypothesis, not only for night driving, but also for driving in general. If that is the case, then we should try to facilitate distance estimation in road traffic. Distance estimation is more difficult at night. Overtaking is probably the most difficult and dangerous driving situation that depends on distance estimation.

Old drivers tend to retain much of their capacity to detect obstacles, but lose much of their peripheral capacity to follow a path or a road. These preliminary findings should be followed up by more extensive research.

Presently, several types of advanced visual enhancements are being considered within the ITS programs around the world. When will they be mature enough to replace some of the vehicle lighting designs of today? How will the interface between driver and equipment be designed to inform the driver about what is in front of him without creating unwanted distraction?

5.5.2 Applied research

The proposal to make the cutoff softer needs to be tested on active roads with realistic vertical and horizontal curves. A first step could be to use visibility models. Field testing would then be performed as needed. How will the detection distances over a stretch of road be influenced by the sharpness of the cutoff for different age groups? Other related variables that need to be studied are the effect of dirt, haze, and aiming on the performance of soft and sharp cutoffs using old subjects.

In this report it has been argued repeatedly that high-performance retroreflective materials should be used more extensively on signs, pavement markings, side-pole delineators, and vehicle and pedestrian markings. This statement is not fully substantiated. We do not know, for example, if a sign or a marking can be too bright. Neither is it known how the material should be used in the most cost-effective way. What effect could colors have (Schumann et al., 1997; Sayer et al., 1998)?

Dual-intensity signaling lights have considerable promise. However, the levels to be chosen have not been studied to such an extent that a decision to implement them can be made at this moment. Furthermore, the suggested, small, high-mounted turn signals are (as far as is known) a new idea that needs to be evaluated before any implementation decision can be made. Will detection of signals be facilitated? How will it influence the visibility/conspicuity of other lights for different age groups?

The goal of the proposed contour marking is to facilitate distance estimation and recognition, especially for old road users. Presently, we have limited knowledge concerning such treatment. Where should it be placed? What lighting characteristics should it have? How much will it improve detection and distance estimation? Will it help old road users more than other age groups?

Another related problem is how corresponding "gestalts" could be designed for two-wheelers and pedestrians in night traffic. Since cyclists and pedestrians are much slower than other vehicles, it is necessary to make them both conspicuous and easily recognized. As seen from the side, the circle seems unbeatable for the two-wheelers. But there is no widely recognized gestalt for the front and the rear of a bicycle, a moped, a motorcycle, and a pedestrian.

Research is already in progress concerning the improved signaling pattern for brake lights. There are many proposals and many technical solutions. So far, none of the proposed designs is generally favored.

The proposal for dedicated optimized DRLs should be further studied. However, that should not delay a decision to make DRLs mandatory. It appears that there is enough evidence that low beams work acceptably as DRLs. An aspect of DRLs that has not been studied is to what extent DRLs may compensate for the impaired hearing of old persons. This question is especially important for old pedestrians and old bicyclists. Maybe such compensation explains a part of the substantial accident reduction unprotected road users achieved with DRLs.

Knowledge about how instruments, controls, and other areas of interest should be lighted seems well developed enough to make adequate designs. But, it would be interesting to know how well improved lighting of controls can compensate for the impaired dexterity of old persons. There are studies showing that old drivers have difficulties reading road signs. Do they have corresponding difficulties reading instruments? That might not be so dangerous in itself. But if instrument reading is difficult, it might take capacity away from the main driving task and thereby impair safety.

Polarized and ultraviolet headlights appear to be less difficult solutions for many of the problems arising from the dilemma between illumination and glare, especially for old road users. Research on these systems should be revitalized, because technological advancements have eased many of the problems that prevented their earlier introduction.

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