Aspects of Safe Road Design for the Aging Road Users

Sophia Vardaki[1], George Kanellaidis[2]

[1]PhD, Senior Researcher
[2]Professor Emeritus

National Technical University of Athens (NTUA)

E-mail:sophiav@central.ntua.gr

Abstract

Road designers and engineers need to apply the knowledge of the ‘human dimension’ in safe road design in order to provide a forgiving environment that reduces the probability of errors. The understanding of these issues is necessary in order for road designers and road safety engineers to make informed decisions for the design of safe road infrastructure. With the increasing participation of older people in traffic over the coming years, it is crucial that professional engineers take into consideration this change and the potential problems it introduces for the traffic system. Road safety engineers and safe road designers need to have similar road safety attitudes and knowledge background; they should understand that road design upgrades and safety treatments work through their influence on human behavior.

Keywords: *Human factors, Safe road design, Road safety, Safe System, Aging road users, Older drivers, Driving behavior, Driving errors.*

Περίληψη

Οι υπεύθυνοι για τον σχεδιασμό και τη λειτουργία των οδών πρέπει να εφαρμόσουν τις γνώσεις για την «ανθρώπινη διάσταση» στον σχεδιασμό ενός συγχωρητικού οδικού περιβάλλοντος που θα περιορίζει την πιθανότητα των λαθών των χρηστών των οδών. Η κατανόηση αυτών των ζητημάτων είναι απαραίτητη προκειμένου οι υπεύθυνοι να λαμβάνουν τεκμηριωμένες αποφάσεις για τον σχεδιασμό ασφαλούς οδικής υποδομής. Με την αυξανόμενη συμμετοχή των ηλικιωμένων χρηστών της οδού στην κυκλοφορία, είναι σημαντικό οι μελετητές και οι μηχανικοί οδικής ασφάλειας να λάβουν υπόψη αυτή την αλλαγή και τα πιθανά προβλήματα που εισάγει στο σύστημα της οδικής κυκλοφορίας. Οι μηχανικοί οδικής ασφάλειας και οι μελετητές έργων οδοποιίας πρέπει να έχουν παρόμοια υπόβαθρα γνώσεων οδικής ασφάλειας και θετικές στάσεις. Θα πρέπει να κατανοήσουν ότι οι αναβαθμίσεις του σχεδιασμού των οδών και τα μέτρα βελτίωσης της οδικής ασφάλειας παράγουν αποτελέσματα μέσω της επίδρασής τους στην ανθρώπινη συμπεριφορά.

Keywords: *Ανθρώπινος παράγοντας, Σχεδιασμός ασφαλών οδών, Οδική ασφάλεια, Ασφαλές Σύστημα, Ηλικιωμένοι χρήστες της οδού, Ηλικιωμένοι Οδηγοί, Συμπεριφορά Οδήγησης, Λάθη οδήγησης*

1. Introduction

Due to their frailty and age-related limitations older road users form a vulnerable group of road users. According to the predicted figures of ageing population in 2050, 35% of the Greek population will be aged 65 or over where as this share was 20% in 2013 (European Commission, 2015). Greece population is getting old; and this seems to be happening fast. Looking at the road fatalities per population (per one million inhabitants) it is evident that during the period from 2010-2016 there was a decrease in average fatalities by population in the EU. In Greece, there was a particular improvement, though it happened on the basis of a very high number of road fatalities by population in 2010, when Greece was the second worst-performing country in the EU, so there is still a lot of room for improvement. Seniors account for 29% of road fatalities in Greece while more than half of the -65 plus- fatalities take place in urban areas and a considerable amount (42%) on rural roads, an admittedly unsafe type of road (www.nrso.ntua.gr).

Data from the Netherlands indicates that the fatality rate of the over-75s is about eleven times higher per kilometer travelled than the average fatality rate for all ages; the fatality rate of the 60-74 year olds is much lower (SWOV, 2015). Taking the distances travelled into account, the fatality rate for older car drivers is more than five times higher for the 75 years and older than for the average for all ages; That of the 65 to 74-year-olds is much lower (European Commission 2019). The most important cause of this high fatality rate among the over-75s is their greater physical vulnerability. Due to functional limitations they are more often involved in crashes while turning left at intersections: the older driver does not give way to traffic going straight ahead because he either estimates the speed of the approaching vehicle incorrectly, or simply fails to notice it. Individual increased crash risk is related to the combined deterioration of a number of relevant perceptual and cognitive functions (rather than to the deterioration of single functions) such as a decrease in depth and motion perception (necessary to determine speed and distance of approaching traffic) and a decline in divided and selective attention (SWOV 2010, European Commission 2019).

The increasing participation of the elderly road users in traffic will result in a greater risk of casualty. Despite the potential of vehicle technologies to prevent road crashes and compensate driving errors, they are viewed as a difficulty, even for the healthy older adults unfamiliar with technology. Moreover, until these vehicle technologies fully penetrate the vehicle fleet there will be a need for a forgiving road environment.

One key to address the safe mobility of the active older drivers is the provision of a safe road infrastructure for this vulnerable and growing part of the population. This paper presents key human factor aspects and safe road design principles, which are particularly relevant to the limitations and characteristics of older road users. These principles and design considerations are derived from a review of modern scientific literature on human factors and Safe System approach. This work refers to the formulation of those principles the understanding of which ensures proper design decisions are made in order to implement a forgiving / safe road infrastructure for this vulnerable and growing part of road users.

2. Methods

We determined the most prominent safe road design considerations on the basis of the conceptual framework presented in Figure 1.

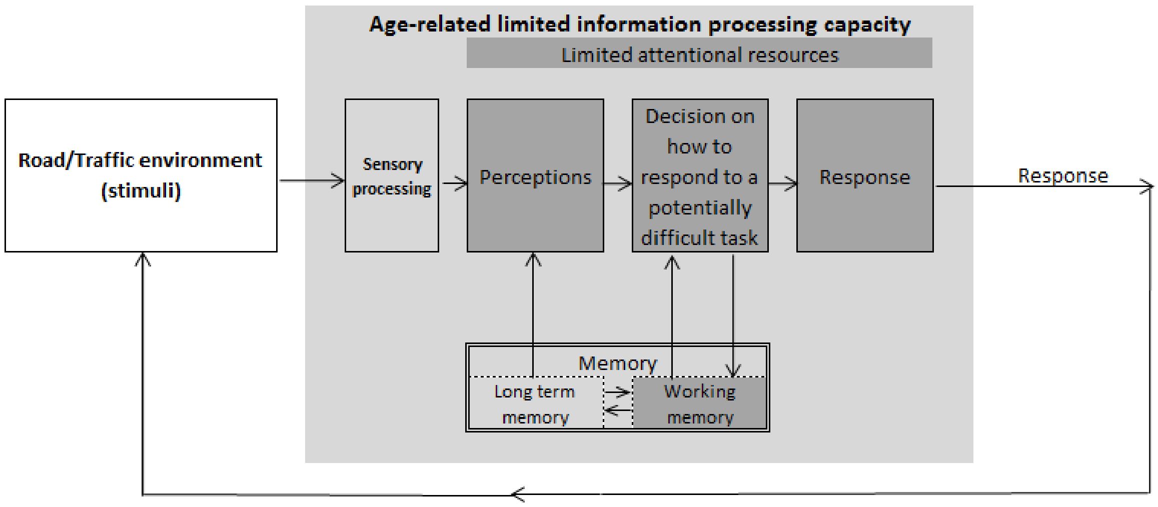

Figure 1: *Relationship between age and unsafe responses (adapted from Wickens in Theeuwes et al., 2012)*

This framework was inspired by the human information processing model of Wickens (Theeuwes et al. 2012), and expresses, in a simplified way, the phases of information processing and the hypothesized relationship between aging and potentially unsafe driving responses (unintentional errors) mediated through driving difficulties. Older persons manifest age related limitations in attentional resources that would induce driving difficulties and, by extend, potentially unsafe driving actions/responses. The present analysis is focused on human factor aspects and principles that guide a safe road design favorable to older drivers with the potential to prevent unsafe -unintentional responses and discourage errors.

3. Safe Road Design for the Aging Road Users

3.1 Human-centered design

The Safe System approach and Vision Zero are two identical human factor strategies (Larsson et al., 2013) that aim for the virtual elimination of death and serious injuries. In the Safe System approach the frailty and fallibility of the road users are recognized. Specifically the basis of the Safe System lies on the following principles (OECD/ITF, 2016):

- Road users make mistakes and the transport system must accommodate these.
- Human bodies have limited capacity to absorb impact force before injury occurs. The road system (the interaction between road design, traffic management, traffic rules, road users and vehicles) should be forgiving of human error and frailty.

- A human error should not result in death or serious injury.
- Use of the system should result in no deaths or serious injuries as a consequence of road user errors.

According to the Safe System approach, death and serious injury in road accidents are largely preventable. This approach entails a new way of thinking and should be reflected in safe road design: The road environment and driver requirements imposed by it should be adjusted to the level that the majority of road users can cope with, thus preventing inadvertent mistakes.
In a Safe System approach, it is emphasized that whatever the efforts made to prevent accidents by changing road users' behaviour, (through education, enforcement, regulation information), crashes can never be entirely eliminated because the road environment is complex for the road users to cope with. One thing to stress is that road design has been highlighted as the most critical area for improvement. Improvements to infrastructure and vehicle safety are most likely to reduce the incidence of fatal outcomes. The new thinking is expressed by the fundamental principle that the road users adjust their driving behavior to the road environment they perceive and expect, and therefore their behavior depends on the road design. In effect, the safety provided by a road design depends on the extent to which it allows road users to make good decisions.

3.2 Physical vulnerability

The road safety of elderly road users is to a large extent determined by two factors: physical vulnerability and functional limitations. Impact speed is a primary determinant of injury outcome. Increases in speed result in increases of both the likelihood of a casualty crash occurring and the severity of injury to the crash participants (OECD/ITF, 2016; Austroads, 2018).

The Safe System Speeds are the critical speeds above which - depending on the crash type- the chance of surviving a crash decreases markedly and are the critical parameters in safe road design. The following speeds are the Safe System speeds, which have achieved practical application in the Netherlands, Sweden and Australia:

- 30 km/h - Where there is the possibility of a collision between a vulnerable road user (pedestrian or cyclist) and a passenger vehicle. Design features that support the vision of vulnerable from vehicles and ensure 30 km/h vehicle speeds; segregation where speeds are high.
- 50 km/h - Where there is the possibility of a right angle collision between passenger vehicles. If this cannot be satisfied then separate, or reduce the angle, or reduce the speed to 50 km/h.
- 70 km/h - Where there is the possibility of a head on collision between passenger vehicles. Car occupants should not be exposed to oncoming traffic (other vehicles of approximately same weight) at speeds exceeding 70 km/h or 50 km/h if oncoming vehicles are of considerably different weight/mass. If cannot be satisfied then separate, homogenise weights or reduce speeds to 70 (50) km/h.
- Speeds can be higher than 100 km/h where side or frontal impact between vehicles or impact with vulnerable road users are not possible.

These speeds address only fatalities and do not account for young and elderly people and heavy vehicles. It should be noted that research in this area is ongoing. Current indications show that impact speeds below around 20 to 30 km/h are necessary to prevent severe injury from occurring. Yet the needs of the most vulnerable , i.e., the elderly and children are not well understood. Undoubtedly their limitations need to be considered in road system design.

Apart from countermeasures that protect road users on making errors such as sealed shoulders, roadside barriers, adequate clear zones and divided road layout, countermeasures that can discourage errors may benefit road users; self-explaining road treatments, user friendly intersection layouts, perceptual countermeasures to name but a few.

3.3 Age-related functional limitations and compensation

Research studies indicate important driving difficulties and weaknesses that are a concern as part of normal aging. These include: Difficulty judging whether other road users are moving and at what speed they approach intersections (motion perception and contrast sensitivity); overlooking other road users while merging and changing lanes (peripheral vision and flexibility of head and neck); overlooking traffic signs and signals (selective attention) and increased reaction times as the complexity of the traffic situation increases (speed of processing information and decision making, divided attention, performance under pressure of time (Theeuwes et al., 2012).

These limitations may affect driving performance but do not lead automatically to higher accident risk because many older drivers tend to compensate. Compensatory behaviors are mostly available on the higher task levels. At the strategic level a road user can decide when and where to travel (avoiding rush hour, driving at night). Self-regulation of driving (Transportation Research Board Circular [TRB], 2016) is a normal process for older adults as they modify their driving to compensate for age-related decline.. At the tactical level, a driver can decide to leave bigger gaps and to drive more slowly. As long as they are not affected by serious disorders as a result of e.g. dementing illness, their experience allows them to be proactive in avoiding complex situations (Dickerson et al. 2017).

According to Fuller's task-difficulty homeostasis model (Fuller et al 2002; Fuller, 2008 in Theeuwes et all. 2012), drivers match capability and task demand to maintain an acceptable task difficulty in all driving situations. When drivers perceive that their competence is less than the demands of the situation, they adjust their behavior to restrict the task demands on the different levels of the hierarchical driving task to make the task easier. An example would be the avoidance of unprotected left turns. The driver's capability to make a correct assessment of driving difficulty (i.e., assessment of the potential road hazards or task demands) and their performance capabilities is crucial from a safety perspective (Dogan et al. 2012).

3.4 Perception of road environment

Road users can receive and process only a finite amount of information in a short period of time and may be adversely affected when road design and / or traffic control features are not appropriately coordinated. The way that road users process information has implications for road design and information provision.

How road users scan the environment seeking for the most meaningful information (Campbell et al., 2012) (i.e., by searching the road environment in front of, behind, and to the sides of the vehicle they are driving) depends on the presence (or absence) of potentially hazardous situations as they perceive them. Road users' capabilities, needs and limitations (e.g. expectations, workload, field of view) affect whether they perceive and correctly interpret road alignment, signs, traffic control devices, etc.. Time is required to detect decide and initiate a maneuver. Road elements and human elements, such as age, information processing, driver alertness, driver expectations, and vision, affect the time and distance needed by a driver to respond to a stimulus (e.g., hazard in road, traffic control device, or guide sign). According to AASHTO (2011), some drivers need as long as 2.7 seconds in order to perceive and respond to unexpected situations.

Older drivers need additional time to plan and execute the necessary maneuvers. An example of integrating time (decision time) into road design and traffic engineering is the decision sight distance (DSD). It is usually necessary in demanding conditions where drivers have to make instant or complex decisions, or where the information provided is difficult to notice. The DSD specifically provides more time so that drivers can do the following: Detect an unexpected or difficult-to-perceive information source or condition in a roadway environment that may be visually cluttered; recognize the condition or the associated risk; select an appropriate speed and path; execute the appropriate maneuver safely and efficiently. The time values used to calculate the decision sight distance vary depending on whether the location is on an urban or rural road and on the type of avoidance maneuver necessary for proper negotiation of the challenging situation (AASHTO, 2011).

Figure 2 is an image of what was originally designed as a through road that today also serves access to tourist attractions and developments at some locations along the coast. Speeds remain at high levels even along these areas with urban characteristics. Supposing a driver, who is not familiar with the road or the place, attempts to enter the through road -with high speed traffic- from a side road that intersects with the main road at a skew angle. Older drivers may find it more difficult to turn their heads, necks, or upper bodies for an adequate line of sight down an acute-angle approach. The driver's sight angle for convenient observation of opposing traffic and pedestrian crossings is decreased. Drivers may have more difficulty aligning their vehicles as they enter the cross street to make a right (or left turn). The driver aligns his car at more favorable angle and waits to find an acceptable gap in the high speed traffic on the main road. He checks turning his head car over his shoulder to the left. A vulnerable road user at the bus stop at an unexpected place (at the periphery of the visual field) may not be detected and possibly a crash could happen.

Figure 2: *A vulnerable road user at the bus stop at an unexpected place (at the periphery of the visual field) may not be detected*

3.5 Driving task complexity/ Workload management

The difficulty of the driving task is related to the capability of the driver at that time and the requirements/demands imposed by the driving conditions. Driver workload refers to the effort made by the driver while driving and varies with the difficulty of the driving task.

Too much workload results in stress, too little results in a low arousal level of the driver. Drivers perform best under moderate levels of driver workload, while they make more errors under low- or high-workload environments. Task overload exists when the demand exceeds a driver's processing / attentional resources; it may lead to panic reactions, severe breaking, erratic maneuvers.

Sudden increases of driver workload contribute to a greater likelihood of making mistakes and increased risk of accidents. These are related for example with considerable changes in the road alignment, and sight distance. When an unexpected event happens and there is an enormous pressure of time to react immediately, workload may also rise quickly. On occasions when information must be processed in a relatively short time, there is little margin for the driver to notice important information from the road environment, and thus a greater likelihood of making mistakes.

Studies have showed increased driver age to be associated with higher rates of crashes involving left turns, particularly at intersections controlled by stop signs or yield signs as opposed to traffic signals. Through appropriate design (Brewer et al. 2014) intersection negotiation can be performed in parts (e.g. crossing the road in phases), in which the elderly can repeatedly assess the situation from a safe place and can themselves determine the time pressure. Complex tasks can be simplified through design that enables the driver to perform the task in a self paced way and separate the driver actions. This is an important design requirement for intersections, particularly relevant to older road users.

The processing time increases if driver expectations are not met. In this case, as studies have shown, their inability to anticipate potential dangers can lead to collisions. In terms of successful workload management, this means that it is crucial for drivers to be able to anticipate any increase in the workload. Increase in workload is mostly associated with tasks that need to be performed at the maneuvering level, which involves interactions with other road users and are associated with visual rather than cognitive workload increases. Workload can increase with adverse weather conditions or unclear road markings, and where there is uncertainty about how to behave. When overload becomes imminent drivers engage in compensatory strategies. However, problems may arise when these are associated with ignoring vital driving tasks.

Older drivers have lower workload capacity. When demands are too high, they may skip or ignore tasks that are not immediately necessary in order to protect the main task performance from decline. Problems may arise when vital aspects are ignored, i.e. drivers may not check mirrors, or look over their shoulder or scan for potential hazards in the immediate environment. In overload conditions, older drivers may choose to selectively use particular information such as directing their attention to the car in front when attempting to merge at a busy high speed motorway (in rainy conditions). In order to minimize attention sharing they may allow the vehicle ahead to vacate access lane before starting to monitor gap. In such cases, dangerous situations may occur such as late merges with inappropriate speeds or accepting unsafe gaps (Theeuwes et al., 2012).

3.6 Supporting the driving task

An important design consideration is the separation of both information provision and task execution in place and time, recognizing that each level of the driving task has its own human information processing requirements. When operating in the knowledge-based performance mode (such as driving in an unfamiliar environment), for example, at a complex motorway interchange, drivers first need information on directional choices in order to decide whether or not to take action. Then they have to orientate themselves to prepare for the desired lane choice at the guidance level and interact with traffic making a speed choice. Finally, this speed and lane maneuver has to be conducted at the control level. Each of these steps takes time and should be made possible by providing information in the right order and with enough time to accommodate them (Theeuwes et al., 2012).

The following example (as presented in Fig. 3) concerns the distinction between the different levels of the driving task and the notion that each level has its own information processing requirements. This photo is taken from the point of view of a driver just before a tunnel entrance. The sign presents information regarding an upcoming exit to multiple destinations and links information at the navigation level with information at the guidance/tactical level.

Figure 3:*Tunnel entrance-conditions of high workload (image from google maps)*

Drivers experience tunnel entrances as high workload situations that may result in stress and uncertainty. Visual scan patterns and physiological measures indicate that drivers start preparing for tunnel entrance 200 meters in advance, i.e during the information presentation distance. At such locations the task at the guidance level requires extra attention- drivers pay attention to negotiating the tunnel entrance itself. Information that is relevant for the navigation level of the driving task may be missed.

3.7 Consistency and Self explaining roads

The current version of Sustainable Safety (SWOV 2018) has the human factor as a starting point and specifies three design principles, namely: the principle of functionality of roads (mono-functionality of roads); the principle of (bio)mechanics: limiting differences in speed, direction, mass and size, and giving road users appropriate protection; and, the principle of psychologics: aligning the design of the road traffic environment with road user competencies. Concerning these safe road design principles, vulnerable road users (pedestrians and cyclists in particular) and the competence of older road users is explicitly considered. These safety principles often linked to more than one type of measure and are operationalised into safety criteria.

In summary, the Sustainable Safety stresses the role of planning and design of the infrastructure. Functionality of roads is the first key safety principle, underlining the importance of functional hierarchy for road safety. According to the functionality principle a road can be a through road or an access road but not both. These two functions pose conflicting road design requirements. In situations where traffic has an exchange function, different transport modes mix, motorized traffic will drive at a low, safe speed in order to minimize crash risk and potential for injury, particularly to vulnerable road users. The road layout and the vehicle help achieve these lower speeds. The safety of senior road users can be ensured with proper neighborhood planning, proper layout, safe speeds and being physically protected. The determinant for what can be considered as ‘safe’ is the most vulnerable or least protected road user that is reasonably expected in the traffic interaction (principle of (bio)mechanics). This safe travel speed should be accounted for in the design of the road, the road environment, and/or the vehicle (the principle of psychologics). Where sufficient compatibility between (bio)mechanic characteristics lacks, additional integrated safety solutions and measures should be implemented to prevent crashes (e.g., physical separation of directions, low speeds, safe shoulders, automatic braking systems) and to limit the injury impact (e.g.,low speeds, removing or shielding obstacles, protection by means of the vehicle, protection by means of protective devices on the body). According to the design principle of psychologics the road environment supports road users' expectations and the traffic system is adjusted to the competencies of seniors (SWOV, 2018).

Research on driver errors and accidents have shown that it was not the delayed or incorrect reactions of drivers that led to accidents; the reason was that drivers did not react at all. The key to workload management is to anticipate the moment at which the workload increases. Consistency and Self-explaining roads (SERs) are key concepts in safe road design (Kanellaidis, 1996; Kanellaidis et al., 2011). They are associated with road layouts and traffic situations that are in line with older drivers' experience-based/a priori expectations (e.g according to their ad hoc expectations of the road that have developed based on the section upstream). SERs allow routine based performance without much effort and thus with fewer driver errors. In SERs the elderly can use their experience and existing automatisms (Theeuwes et al., 2012).

Ideally, safe driving behavior is induced by the road itself. In the sustainable safety approach (SWOV, 2018; Theeuwes et al., 2012) each road should be designed as far as possible to be Self-explaining according to its function, reducing the chance of uncertain behavior. Information about the prevailing conditions of the traffic system is transferred to the road users by the road layout, the road environment, traffic signs and regulation, via the vehicle and via technology. Two fundamental criteria that have to be met by a Self-explaining road classification are homogeneity within and heterogeneity between road categories, which means that SERs must be recognizable, distinguishable, interpretable and safe. An important SER principle concerns the transitions between roads of different functions/ categories; while the transition should not be fast it should be marked clearly. Perceptual countermeasures support these transitions with the aim to influence drivers' perception of their speeds and task difficulty (Campbell et al. 2012; Theeuwes et al., 2012).

Roads designed along the SER principles should elicit safe behavior/safe speeds simply due to their *perceived* design and without further need on the side of the driver to elaborate the required behavior. In this way less behavioral adaptation is expected in Self-explaining roads.

3.8 Positive guidance

A measure that addresses the problem of information overload that is likely to benefit older drivers is to give clear guidance of how to behave: where to go, at what speed, etc. Clear sight lines, hazard visibility and consistency in road design (i.e., consistency in cross section, operating speed and driver workload meeting driver expectancy), are fundamental safe road design principles, markedly important for older road users (Alexander et al., 1986). With respect to traffic control devices, the application of fundamental positive guidance principles (i.e., primacy, spreading, coding and redundancy) at the three levels of the driving task ensures provision of information adapted to road users' needs/limitations. Conspicuity of information elements and messages as well as recognition, readability and comprehension are essential in order to meet driver expectancy. Uniformity in behavior rules and consistency in their application reduces driver error.

The problems that older drivers may encounter in perceiving and interpreting information are addressed through information elements that are timely visible, recognizable and legible in the first instance and can be comprehended in an unambiguous manner. The older road users need clear and advance information about the approaching traffic situations because they generally need more time to perceive motion, make decisions and carry out tasks. Timely information gives the road user more time to prepare and interact with important infrastructural features. Advance information with adequate size, good lighting and clear road markings, lightning and glare protection for legibility, visible layouts and lane configurations, type of traffic control (Theeuwes et al., 2012; Campbell et al., 2012).

Elderly drivers require advance and clear roadside information particularly at roadworks. Driving along a road work zone represents a highly demanding driving task associated with violation of driver expectations due to unusual features, significant changes in alignment, discontinuities in road markings, gaps, obstacles and traffic control devices placed close to the drivers' path, as well as road equipment and materials placed in and around the work zone.

Fig.4a, depicts the presence of visual clutter, due to work zone lights and workzone vehicles' lights, can obscure important signing and delineation information; longitudinal pavement joints that do not coincide with the temporary travel lane lines. A location of high information load is presented in Fig.4b: Multiple permanent and temporary signs in the driver's visual field: Traffic control devices and channelizing devices /delineators adjacent to traffic.

In Figure 4c, it is evident that any erroneous actions at the skill-based task-performance level (at the guidance and control levels of the driving task, such as maneuvering between delineators) may rapidly result in safety-critical situations. The workzone sign for lane shift provides more critical information than the sign with navigation information (regarding the distance to the next exit that follows the deviation). Consequently, when determining the appropriate sign placement and the distances between the signs (information presentation distance), it is important to consider factors related to driver such the criticality (primacy) of the information to be presented, the sign information complexity and the required maneuvers, which, in turn influence driver decision and maneuver time.

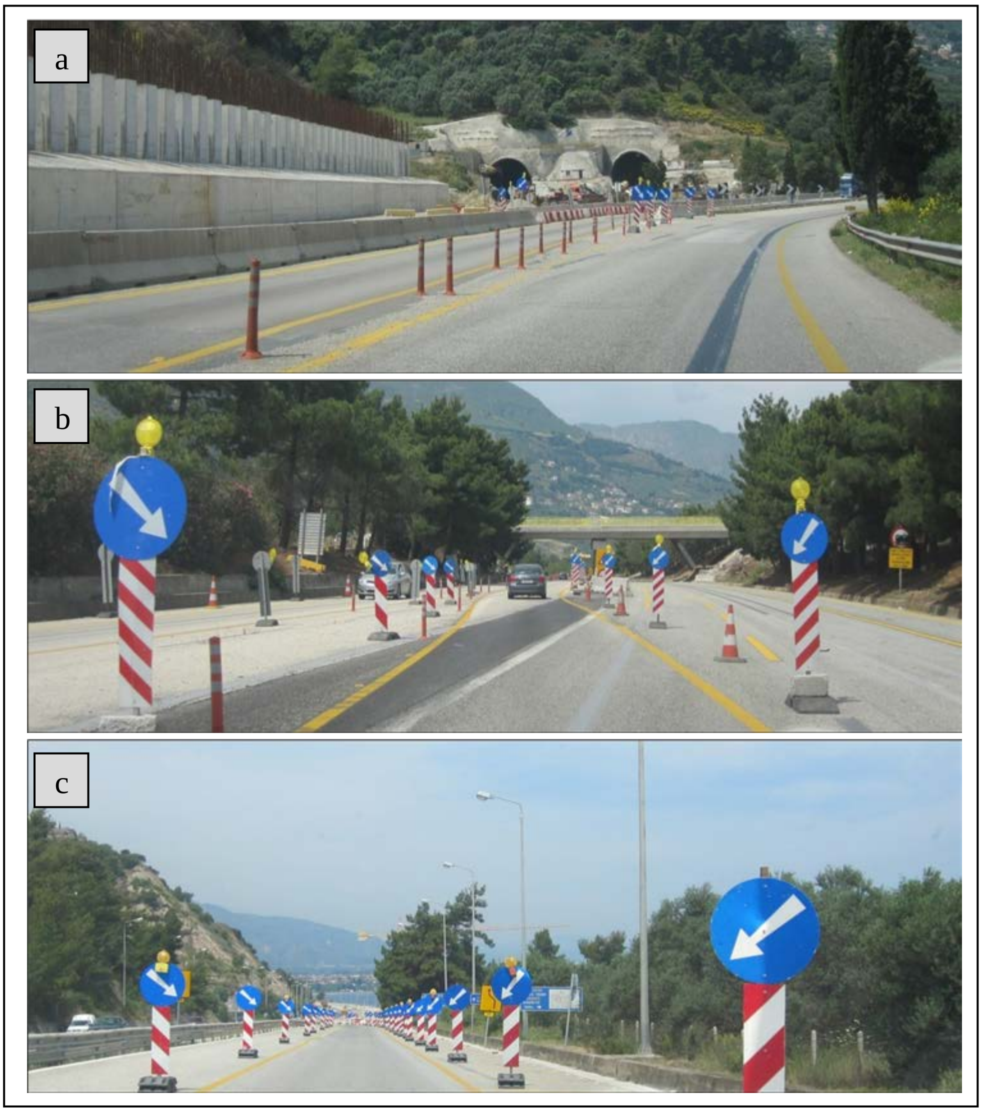

***Figure 4:** Driving along a workzone - a highly demanding driving task*

4. Infrastructural countermeasures

Functional limitations and physical vulnerability contribute to the relatively high fatality rate among elderly road uses in crashes. With respect to the infrastructural interventions several safety countermeasures that accommodate older drivers' needs and characteristics can be found in existing publications, i.e., Guidelines in USA and Australia relevant research reports (Brewer et al. 2014; Staplin et al. 2001; Fildes 1997; Fildes et al 2000; Davidse, 2007). Based on the problems of elderly drivers the, promising infrastructural measures include:

- Intersection design, i.e., providing a good and early view on the intersection; assistance in making a left turn; roundabouts
- Road signs and markings
- Traffic lights and fixed lighting
- Exits and entries of motorways

As functional limitations become prevalent with age, it is necessary that infrastructure provides the driver with enough time to observe, decide and act; also, the design of infrastructure should comply with road users' expectations. These prerequisites for improving the road safety for older road users are aligned with the principles of Safe System and Sustainable safety principles. However, it is important that infrastructural interventions meet specifically the needs of older road users. This mainly entails that

- infrastructure elements should provide the driver more time (e.g. long acceleration lanes on motorways and large stopping sight distances at intersections);
- designs should allow older drivers to use their experience and existing automatisms;
- infrastructure designs should make the driving task easier: increased letter-height and retro reflectivity of street name signs, good lighting, and a higher contrast between pavement markings and the carriageway make it easier to observe, decide and act;
- complex tasks can be simplified by giving the opportunity to older drivers to perform the task parts (e.g. crossing the road in phases), being able to determine the time pressure themselves.

5. Summary

The key principles and safe road design considerations presented in this paper address age-related needs and limitations and are summarized as follows:

- Road users' capabilities, needs and limitations (e.g. expectations, workload, field of view) affect whether they correctly interpret road alignment, signs, traffic control devices, etc..
- Road elements and human elements, such as age, information processing capacity, driver alertness, driver expectations, and vision, affect the time and distance needed by a driver to respond to a stimulus (e.g., hazard in road, traffic control device, or guide sign).
- Road users may be adversely affected when road design and / or traffic control features are not appropriately coordinated.
- Consistency in design and Self explaining roads (SERs) are associated with road layouts and traffic situations that are in line with older drivers' (experience-based) expectations.
- Appropriate road design that simplifies complex driving tasks, enabling the driver to perform the task in a self paced way (in parts), is an important design requirement that benefits older road users, whether they are drivers or pedestrians.
- In changes of function or category of a road, signing alone is not sufficient to induce appropriate speed behavior if it does not correspond to the way in which the driver perceives and categorizes the situation. Drivers make larger speed adjustments where the transitional situation clearly serves the purpose for which it is designed.

- SERs allow routine based performance without much effort and thus with fewer driver errors.
- Roads designed along the SER principles should elicit safe behavior/safe speeds simply due to their perceived design and without further need on the side of the driver to elaborate the required behavior. In this way less behavioral adaptation is expected in Self-explaining roads

6. Discussion

Safe road design needs to reflect Safe System and human factor principles. There is a need for a smooth, though rather long, transition (Kanellaidis & Vardaki 2017) to transform the traditional approach to road design through a Safe System perspective. This transitional period is necessary for integrating the concepts that reflect the new holistic and anthropocentric approach to road safety into design guidelines.

With the increasing participation of older people in traffic over the coming years, it is crucial that traffic professionals/engineers take into consideration this change and the potential problems it introduces for the traffic system. Human-centered design requires that road engineers are willing to learn about (and be well aware of) human limitations and motivations. Road safety engineers and safe road designers need to have similar road safety attitudes and knowledge background; they should understand that road design upgrades and safety treatments work through their influence on human behavior. During the transitional phase, road designers and engineers need to attend extensive and transformative professional development courses underpinning road safety culture that will enable them to conceive Safe System principles and apply modern effective road safety practices that address 'human dimension' in road design (Vardaki et al., 2018).

The current edition of Sustainable Safety more explicitly emphasizes the specific responsibilities of different road safety stakeholders who have a crucial role in realizing a sustainably safe road traffic system. With respect to safety measures implementation, the commitment of road authorities and other traffic professionals to the aim of the sustainable safety is expressed through the application of modern road safety practices and effective measures and also the dedication of time to road safety education and training. Road traffic professionals and safe road designers particularly should continually learn how they can improve their policy and methods and learning processes can be systematized within organizations. The formulation of an education and training framework is important in this regard.

6. References

AASHTO (American Association of State Highway and Transportation Officials) (2011). *A Policy on Geometric Design of Highways and Streets*. Washington D.C..

Alexander, G., A., & H. Lunenfeld (1986). *Driver Expectancy in Highway Design and Traffic Operations*. Technical Repot FHWA-TO-86-1, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C.

Austroads (2018). *Towards Safe System Infrastructure: A Compendium of Current Knowledge*, Austroads Publication Research Report AP-R560-18, Sydney.

Brewer, M., D. Murillo, & A. Pate, A. (2014). Handbook for Designing Roadways for the Aging Population. Report No. FHWA-SA-14-015, Federal Highway Administration (FHWA), Washington, DC.

Campbell, J. L., M. G. Lichty, J. L. Brown, C. M., Richard, J. S., Graving, …& Harwood, D. (2012). *Human factors guidelines for road systems* (NCHRP Report 600) (Second Edition), Transportation Research Board of the National Academies, Washington, DC.

Davidse, R. J. (2007). Assisting the older driver: Intersection design and in-car devices to improve the safety of the older driver (PhD thesis). University of Groningen, The Netherlands.

Dickerson, A. E., Molnar, L. J., Bédard, M., Eby, D. W., Berg-Weger, M., Choi, M., . . . Silverstein, N. M. (2017). Transportation and Aging: An Updated Research Agenda to Advance Safe Mobility among Older Adults Transitioning From Driving to Non-driving. *Gerontologist*. doi:10.1093/geront/gnx120

Dogan E, Steg L, Delhomme P, Rothengatter T. (2012). The effects of non-evaluative feedback on drivers' self-evaluation and performance. Accident Analysis and Prevention.45:522-8. doi: 10.1016/j.aap.2011.09.004.

European Commission (2015). ElderSafe - Risks and countermeasures for road traffic of the elderly in Europe. Final report . N° MOVE/C4/2014-244.

European Commission. High fatality rate: more crashes or more severe injuries? https://ec.europa.eu/transport/road_safety/specialist/knowledge/old/older_drivers_risky_or_at_risk/common_crash_types_among_older_drivers_en-. Accessed 18th August 2019.

Fildes, B. (1997). Safety of Older Drivers: Strategy for Future Research and Action Initiatives (No. 118). Victoria, Australia: Monash University Accident Research Centre.

Fildes, B., Corben, B., Morris, A., Oxley, J., Pronk, N., Brown, L., & Fitzharris, M. (2000). Road safety environment and design for older drivers (No. AP-R169). New South Wales, Australia: Austroads.

Fuller, R. and Santos, J.A. (2002). Human Factors for Highway Engineers, 1st Ed., Pergamon, Oxford.

Kanellaidis G., & S. Vardaki (2011). Highway geometric design from the perspective of recent safety developments. *ASCE Journal of Transportation Engineering*, Forum piece, 137 (12), 841-844.

Kanellaidis, G. & S. Vardaki (2017). Road Design through a Safe System Perspective. Proceedings of the 8th International Congress on Transportation Research in Greece, *Transportation by 2030 Trends and Perspectives.* September 27-29, 2017. Thermi, Thessaloniki.

Kanellaidis, G. (1996). "Human Factors in Highway Geometric Design". *ASCE Journal of Transportation Engineering*, 122 (1), 59-66.

Larsson, P., &C. Tingvall (2013). The Safe System Approach – A Road Safety Strategy Based on Human Factors Principles.*Engineering Psychology and Cognitive Ergonomics. Applications and Services*. Volume 8020 of the series Lecture Notes in Computer Science, D. Harris (Ed.). DOI10.1007/978-3-642-39354-9_3, pp 19-28.

OECD/ ITF (Organisation for Economic Cooperation and Development / International Transport Forum) (2016). *Zero Road Deaths and Serious Injuries: Leading a Paradigm Shift to Safe System*. Organisation for Economic Cooperation and Development / International Transport Forum.

Staplin, L., Lococo, K., Byington, S. & Harkey, D.L. (2001) Highway design handbook for older drivers and pedestrians. FHWA-RD-01-103. U.S. Department of Transportation DOT, Federal Highway Administration FHWA, Turner-Fairbank Highway Research Center Research and Development RD, McLean, VA.

SWOV (2018). Sustainable Safety 3rd edition *The advanced vision for 2018-2030*. ISBN: 978-90-73946-17-0 2018

SWOV Institute of Road Safety Research (2015). Fact sheet The elderly in traffic. August 2015. https://www.swov.nl/en/print/facts-figures/factsheet/elderly-traffic. Acessed 18th August 2019.

SWOV Institute of Road Safety Research. Fact sheet The elderly and infrastructure. April 2010. https://www.swov.nl/publicatie/elderly-and-infrastructure. Accessed 31st August 2019.

Theeuwes, J., R Van DerHorst, and M. Kuiken, M. (2012). *Designing Safe Road Systems*, Ashgate.

Transportation Research Board of the National Academies of Science (2016).Engineering and Medicine. Taxonomy and terms for stakeholders in senior mobility. In *Transportation Research Circular, Number E-C211*, Transportation Research Board: Washington, DC.

Vardaki, S., Bekiaris, E., & Kanellaidis, G. (2018). Addressing education and training needs of road safety auditors. *Cogent Engineering*, *5*(1), 1525814. https://doi.org/10.1080/23311916.2018.1525814

Reference in greek language:

HIT (2015). Development of Training Curriculum and Educational Material for Candidate Road Safety Auditors, Deliverable 2 Educational material (November, 2015) Hellenic Institute of Transport of the Center for Research and Technology Hellas funded by the Greek Ministry of Infrastructure, Transport and Networks.

Θέματα Ασφαλούς Σχεδιασμού των Οδών για τους Ηλικιωμένους Χρήστες

Σοφία Βαρδάκη[1], Γεώργιος Κανελλαΐδης[2]

[1] Δρ. Αγρονόμος Τοπογράφος Μηχανικός
[2]Ομότιμος Καθηγητής

Εθνικό Μετσόβιο Πολυτεχνείο
Σχολή Πολιτικών Μηχανικών
Τομέας Μεταφορών και Συγκοινωνιακής Υποδομής

E-mail:sophiav@central.ntua.gr

Εκτεταμένη Περίληψη

Η ευπάθεια και οι περιορισμοί στις λειτουργικές ικανότητες καθιστούν τους ηλικιωμένους χρήστες των οδών μια ευάλωτη ομάδα χρηστών. Επιπλέον, αναμένεται η συμμετοχή τους στην κυκλοφορία να αυξηθεί σημαντικά τα επόμενα χρόνια γεγονός που θα έχει ως αποτέλεσμα μεγαλύτερο κίνδυνο θανάτου ή σοβαρού τραυματισμού σε οδικά ατυχήματα. Παρά τη συμβολή της τεχνολογικής εξέλιξης των οχημάτων στην αποτροπή των οδικών ατυχημάτων και στην αντιστάθμιση των λαθών οδήγησης, η χρήση της νέας τεχνολογίας θεωρείται ως παράγοντας δυσκολίας ακόμη και για τους υγιείς ηλικιωμένους, που όμως δεν έχουν τη σχετική εξοικείωση με την τεχνολογία. Η ασφαλής κινητικότητα των ηλικιωμένων οδηγών με δραστηριότητα οδήγησης σε μεγάλο βαθμό εξαρτάται από το εάν η οδική υποδομή είναι ασφαλής για αυτή την ευάλωτη και διαρκώς αυξανόμενη ομάδα του πληθυσμού. Στόχος της εργασίας είναι η παρουσίαση αρχών για τον ασφαλή σχεδιασμό των οδών και στοιχείων του ανθρώπινου παράγοντα που συνδέονται με τους περιορισμούς των ηλικιωμένων χρηστών της οδού μετά από ανασκόπηση της σύγχρονης βιβλιογραφίας για το ασφαλές σύστημα και τον ανθρώπινο παράγοντα στην οδική κυκλοφορία. Σχετικές θεωρήσεις με βάση τον ανθρώπινο παράγοντα που θα πρέπει να λαμβάνονται υπόψη στον ασφαλή σχεδιασμό των οδών περιλαμβάνουν τα εξής:

- Η σωστή ερμηνεία της χάραξης της οδού και των μέσων ελέγχου κυκλοφορίας εξαρτάται από τις ικανότητες και τους περιορισμούς των χρηστών της οδού.
- Τα στοιχεία της οδού, και του ανθρώπινου παράγοντα (η ηλικία, η ικανότητα επεξεργασίας πληροφοριών, η επαγρύπνιση, οι προσδοκίες του οδηγού κ.λπ.) επηρεάζουν τον χρόνο και την απόσταση που χρειάζεται ο οδηγός για να αντιδράσει σε

ένα ερέθισμα στο οδικό και κυκλοφοριακό περιβάλλον (π.χ. σε ένα κίνδυνο, ή σε μία πινακίδα σήμανσης).

- Οι χρήστες των οδών και ιδιαίτερα οι ηλικιωμένοι μπορεί να επηρεάζονται αρνητικά όταν η χάραξη και τα στοιχεία σήμανσης δεν είναι κατάλληλα συνδυασμένα.
- Η ομοιογένεια στον σχεδιασμό και οι εύκολα κατανοητές οδοί αναφέρονται σε στοιχεία της οδού και κυκλοφοριακές καταστάσεις που ανατποκρίνονται στις προσδοκίες των ηλικιωμένων χρηστών της οδού που έχουν διαμορφωθεί με την εμπειρία τους.
- Ο κατάλληλος σχεδιασμός που απλοποιεί το έργο της οδήγησης, όπου είναι σύνθετο, δίνει τη δυνατότητα στους ηλικιωμένους οδηγούς να επιλέγουν οι ίδιοι το ρυθμό της επιτέλεσης του έργου οδήγησης.
- Σε αλλαγές της καθοριστικής λειτουργίας μιας οδού, η σήμανση από μόνη της δεν είναι επαρκής για να ενθαρρύνει την κατάλληλη συμπεριφορά (π.χ. ταχύτητα) εάν δεν αντιστοιχεί στον τρόπο που ο οδηγός αντιλαμβάνεται και κατηγοριοποιεί την οδό. Οι οδηγοί κάνουν μεγαλύτερες προσαρμογές της ταχύτητάς τους όταν είναι σαφής η αλλαγή της λειτουργίας της οδού.

Οι υπεύθυνοι για τον σχεδιασμό και τη λειτουργία των οδών πρέπει να εφαρμόσουν τις γνώσεις για την «ανθρώπινη διάσταση» στον σχεδιασμό ενός συγχωρητικού οδικού περιβάλλοντος που θα περιορίζει την πιθανότητα των λαθών των χρηστών των οδών. Η κατανόηση αυτών των ζητημάτων είναι απαραίτητη προκειμένου οι υπεύθυνοι να λαμβάνουν τεκμηριωμένες αποφάσεις για τον σχεδιασμό ασφαλούς οδικής υποδομής.