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An in-depth analysis of road infrastructure interventions aiming to improve road safety of the elderly in Europe

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Abstract

This paper presents the findings of an in-depth analysis of infrastructure related risk factors and interventions specific to the road safety of the elderly conducted in the framework of the ElderSafe project, funded by the European Commission DG MOVE. The infrastructure areas considered include highway design, urban and rural roads, traffic control at junctions, road lighting, route guidance and signs. The findings suggest that several interventions in road design have the potential to improve safety of elderly road users, however, only a few seem to address the most critical risk factors of elderly people. The most promising interventions identified include: separation of vulnerable road users from motorized traffic and/or introduction of low design speeds in areas with many vulnerable road users (VRU), the development of self-explaining and forgiving roads in urban and rural areas, the reduction of conflicts between VRU's and vehicles and between vehicles at urban intersections, the use of protected-only operations at signalized intersections, and the development of standards in the area of age-friendly road design.

1. Introduction

In the coming years, Europe is facing a significant shift in the age distributions of populations. By 2050, more than 147 million people aged 65 or over will be living in the European Union. This increased proportion of elderly road users in traffic will bring a significant increase in the number of elderly road users who are at risk of being involved in road accidents. Figure 1 shows the estimated road traffic fatalities among the elderly (≥ 65 years) as a percentage of all traffic fatalities in the EU-27 through 2050.

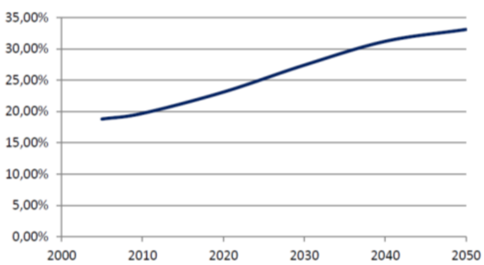

Fig. 1 estimated road traffic fatalities among the elderly (≥ 65 years) as a percentage of all traffic fatalities in the EU-27 through 2050 (source: Elvik et al. 2015).

Road safety of older road users is defined by their age-related physical fragility and functional impairments. These contributory factors combined with the expected demographic changes and the increasing mobility needs

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of the elderly requires a package of best practices targeted at improving the road safety for different older road user groups. One way to ameliorate older road users' safety is to improve the roadway and driving environment to accommodate the characteristics and needs of older drivers. Oxley et al. (2010) underlines that current roadway design principles make few allowances for older drivers' performance. Guidelines targeted to older safety have been drafted for the United States (Staplin et al., 2001) and Australasia (Fildes et al., 2000).

The present paper aims to address the effectiveness and cost-benefit of state-of-the- art interventions related to infrastructure and elderly safety. Within the ElderSafe project, funded by the European Commission DG MOVE, an in-depth analysis of infrastructure related risk factors and interventions specific to the road safety of the elderly was carried out. More than 25 areas of infrastructure interventions were reviewed, with numerous specific interventions, in terms of: (i) effectiveness in reducing the population attributable risk (i.e. number of killed or injured elderly road users or number of crashes with elderly road users); (ii) public support for the measure; (iii) cost of the measure; (iv) importance, i.e. whether the measure addresses a key risk factor for the elderly.

2. A review of infrastructure related interventions for older road users

Several safety countermeasures have been proposed and evaluated with respect to their effect to older road users. These mainly include: i. Highway design parameters, ii. Rural and urban road networks design and operation aspects, ii. Traffic control at intersections, iii. Road markings, iv. Lighting, and v. Route guidance and signs. A summary of the most prominent interventions in relation to the type of road user, the type of vehicle and the type of effect is provided in Table 1. In the following section, these interventions are analytically discussed with respect to their tested effectiveness, their cost and the public support.

Table 1. Summary of infrastructure interventions for elderly safety.

Measures	Road User				Vehicle type			Effect		
	Driver	Passenger	Public transport	Pedestrian	Passenger car	Motorcycle	Bicycle	Exposure	Accident risk	Injury risk
Use of protected-only operations at signalized intersections in urban areas	●			●	●	●	●		●	●
Right-angled junctions in rural areas	●			●	●	●	●		●	
Optimize green-times in signalized intersections in urban areas	●			●	●				●	
Unobstructed view on the intersection in urban and rural areas	●			●	●	●	●		●	
Roundabouts in urban areas	●			●	●	●	●		●	
Roundabouts in rural areas	●			●	●	●	●		●	
Use of advanced warning signs in urban areas	●				●	●	●		●	
Use of advanced warning signs in rural areas	●				●	●	●		●	
Lower design speeds	●				●	●	●		●	●
Conspicuity of traffic signs in urban and rural areas	●				●	●	●		●	
Better road lighting in urban areas	●			●	●	●	●		●	
Better road lighting in rural areas	●			●	●	●	●		●	
Better conspicuity and luminance of traffic signs	●				●	●			●	
Better visibility of road markings in rural areas	●				●	●	●		●	
Fixed lighting at interchanges of motorways	●				●				●	
Longer acceleration and deceleration lanes on motorways	●				●				●	
Self-explaining roads	●				●	●	●		●	
Forgiving roads - Passive safety (e.g. barriers)*	●				●	●	●		●	●
More and wider bicycle tracks in urban areas	●						●		●	
Safe stopping locations for older cyclists in urban and rural areas	●						●		●	
Conspicuousness of obstacles for older cyclists in urban areas	●						●		●	
Decreasing pedestrian crossing distance in urban areas				●					●	
Placing traffic lights at more crossing locations in urban areas	●			●	●		●		●	
Adjusting the traffic lights in urban areas	●			●	●		●		●	
Speed reduction interventions in urban areas	●			●	●		●		●	●
Wider sidewalks in urban areas				●					●	●
Well-maintained road infrastructure in urban areas	●	●	●	●	●	●	●		●	●
Installation of lighting at pedestrian crossings in urban areas				●					●	
Installation of lighting at pedestrian crossings in rural areas				●					●	
Physical separation between pedestrian and traffic lanes in urban areas				●					●	●
Physical separation between pedestrian and traffic lanes in rural areas				●					●	●
Facilities at public transport stops and transit vehicles		●	●					●		

3. Design and operation of road networks

3.1. Highway design

The decision-making, when entering and exiting highways, is significantly influenced by the age-related functional declines, such as systematic decline in visual acuity (Staplin et al. 2001). According to a survey on older drivers, the length of freeway entry lanes was a highway feature that is more important to them now compared with 10 years ago (Benekohal et al. 1992). de Waard et al. (2009), in a simulator experiment, showed that the existence of driver support systems and the extended acceleration lane have positive effects for older drivers. Design speed is used to determine the various geometric features of the roadway. Design speed is a fundamental aspect of highway design and is linked to concepts such as the minimum sight distance, the horizontal curve design criteria and so on (Montella 2009, Wood and Donnell 2014). Elvik et al. (2009) review the effects of design speed interventions to road safety. In general, low design speeds - when these are applied in long road sections – are found to lead to increased number of accidents, due to the induced speed variations (Krammes 1997). In curves, reduced design speeds lead to less in number and severity accidents (Shankar et al. 1995). No results on the effectiveness of lowering the design speeds to older driver's safety are reported.

3.2. Rural and urban road networks: well-maintained infrastructure

Improvements in roadway conditions can make roadway infrastructure more forgiving to older drivers, as well as older pedestrians and Powered-Two Wheelers (PTWs) (NHTSA 2010, ETSC 2008, 2BESAFE 2012). In literature several measures have been implemented for increasing road safety, yet with conflicting outcomes. A typical example is various traffic calming measures, for example use of raised lane markings and lane dividers, as well as barriers and guardrails, may be beneficial for passenger cars and pedestrians, but may have negative safety effects for PTW (DACOTA 2012). Rizzi et al. (2011) state the effectiveness of smooth surfaces to the fatal crashes. As for the cost-benefit analysis, Elvik et al. (2009) underline that the benefit –cost ratio of general improvements of national highways ranges from 0.5 to 1. Scully et al. (2008) reported significant reductions in PTW casualty crashes when treating for black spots. This intervention may lead to a benefit-cost ration of about 15. No results have been documented in literature related to elderly safety and the cost benefit merit of interventions, or the public support of implemented interventions.

3.3. Rural and urban road networks: conspicuity at intersections

Conspicuity at intersection is significantly affected by street angle. A right angle junction is important for older adult road users in particular (Staplin et al. 2001). Skewed junctions are the most problematic for older drivers (Fildes et al. 2000). Classen et al. (2007) evaluated the effectiveness of intersection design for senior adults and showed that in improve non-skewed intersections older driver errors were significantly reduced compared to the unimproved intersections. Mace (1988) reported that intersection channelization projects had an average benefit-cost ratio of 2.3. An obstructed or restricted view of the intersection is an additional difficulty for older road users (drivers, riders and pedestrians). Oxley et al. (2006) argue on the need to design based on longer sight distances at intersections to accommodate older drivers, to provide them more time to select a safe gap in which to turn across, enter or cross traffic. Sight distance improvements at intersection are the most cost effective intervention with a benefit-cost ratio of 5.33 (Staplin et al. 2001). In an FHWA (1996) report, it is stated that that improvements in intersection sight distance have a benefit-cost ratio of 6.1 in reducing fatal and injury crashes.

3.4. Rural and urban road networks: "self-explaining and forgiving roads"

"The self-explaining road" concept encapsulates all possible aspects of road safety and infrastructure design to provide a simple and unambiguous, clear and understandable, readable and recognizable traffic situation (Herrstedt 2001). Examples of self-explaining and forgiving roads include visual flicker and visual narrowing of road lanes created by use of forgiving obstacles, reduced lengths and spacing of center lines, rocking and waving road surface on selected road sections, markings painted to appear three dimensional, rumbling road surface along edge lines and center etc. Forgiving and self-explaining roads are rather complementary concepts; self-explaining roads seek to prevent driving errors, while forgiving roads minimize their consequences (La Torre 2012). Some features of forgiving roadsides are barrier terminals, shoulder rumble strips, forgiving support structures for road equipment, shoulder width. The concepts of self-explaining and forgiving roads extend to all motorized rad users and cyclists.

Herrstedt (2006) concluded that physical dividers along center lines on rural roads resulted in significantly reduced speed in both the mean and the variance, while the frequency of overtaking (legal and illegal) has been also reduced. Wiethoff et al. (2012) identified a series of measures, such as Navigational aid Variable message sign (VMS), VDS, Audio lane warning delineation, Electronic traffic signs, Rumble strips, VMS with fog warning to treat road users errors and showed that the different stakeholders will prefer different types of safety measures. Yet, no special treatment has been proposed in literature for older drivers. Road rumbles significantly reduce single-vehicle run-off-road accidents. The risk associated with the use of 'passively safe' or 'forgiving' lighting columns resulted in a risk almost eight times lower than that associated with conventional unprotected columns (Williams et al. 2008). Restrain mechanisms on the road have been found to be extremely effective with regards to road safety (Bambach et al. 2013): wire-rope barriers lead to a reduction of 40% in PTW fatalities, high roadside barriers (guardrail) may lead to a significant reduction to serious and fatal PTW accidents.

3.5. Road markings

Strategies on improving visibility of road markings focus on providing older drivers with better visual cues (e.g., pavement markings along the roadway, raised channelization at intersections, and delineators at horizontal curves) to recognize roadway elements in order to maintain their lane and to safely negotiate through an intersection or a horizontal curve. Kline et al. (1990) tested young and older drivers with respect to the visibility of text and icon signs under day and dusk lighting conditions and found that there were no age differences in the comprehension of icon signs, but there was considerable variability from one icon sign to another in the degree to which they were comprehended; icon signs appear to offer drivers of all ages almost twice as much time in which to respond to them. Literature also reports crash reductions of 21% with existing longitudinal pavement markings and crash reductions of approximately 8% with painted edge-lines on rural two-lane highways (Miller 1993). No cost-benefit or public support information for interventions dedicated to older drivers and road markings is reported.

3.6. Rural and urban road networks: roundabouts

Literature indicate that older drivers find difficulty to negotiate roundabouts, especially those with multiple lanes due to the lack of relevant information and familiarity of the design rules, signs, marking etc. (Benekohal et al., 1992). Past studies have provided evidence that roundabouts consistently reduce accident probability (Dijkstra and Bos 1997). Persaud et al. (2001) found in the US significant reductions in crash severity at intersections that had been converted from other forms of traffic control (signals, ‘stop’ and ‘give-way’ signs) to roundabouts. Converting an ordinary junction to a roundabout leads to decreases in injury crashes by 32 % for a three-leg junction and 41 % for a four-leg junction, while the corresponding figures are 11 % and 17 % when converting a signalized junction to a roundabout (Elvik et al. 2009).

While roundabouts have been shown to reduce the number of vehicle-vehicle collisions, particularly rear-end, right-angle and left-turn crashes, the evidence regarding their effectiveness as a safety measure for pedestrians and cyclists is less intense (Katz and Smith 1994, Oxley et al. 2004). Jensen (1999) summarized the effects of interventions to pedestrian safety and reported that a well-designed roundabout may reduce pedestrian crashes by 46% to 89%. Pedestrian and cyclist’s safety in roundabouts may be improved with constructing large splitter islands, banning parking near roundabouts, adequate street lighting, speed reduction installations, reduced width of circular carriageway, as well as increased deflection and improved signing.

Constructing roundabouts in order to replace intersection is costly but efficient. An Australian research notes the benefits of roundabouts over other forms of intersection control, stating a benefit-cost ratio typically between 5 and 8 (Corben et al., 2001). The benefit-cost ratio when converting a typical three or four leg junction to a roundabout is around 1 (Elvik et al. 2009).

3.7. Rural and urban road networks: flows’ separation

Pedestrian safety is generally found to improve in the presence of physical separation of pedestrians from vehicle traffic, when using underpasses and overpasses, regardless of the discomfort that most pedestrian, especially the older, feel due to the difficulty in climbing steps etc (Retting et al. 2000). Barriers and fences designed for pedestrian flow channelization to safe crossing areas have been found to reduce mid road crossing and substantially decrease collision rates for pedestrians of all ages (Stewart 1988). A report in the framework of SAMARU (2012) underlines the strong views expressed by older pedestrians related to the circulation of bicycles in sidewalks.

In high speed rural roads barrier systems have the potential to reduce fatal crashes and serious injury crashes by approximately 90% with a benefit-cost ratio of around 8 (Oxley et al. 2004a). In a recent project report, the infrastructure design which jointly considers pedestrian and cycling flows in a ‘shared space” is found to be not always advantageous, especially for older road users who may feel unsafe and may, therefore, avoid using such sections (GOAL 2013b).

At intersections, for older pedestrians, empirical evidence related to refuges are not clear. Studies have suggested that central refuges refuge islands, side-road junctions and major junctions, decrease conflicts in two way streets (Coffin and Morrall 1995, Oxley et al. 1997, Henderson 2003, Oxley et al. 2004a), whereas others on the provision of a side road refuge with kerb may lead to a change in all pedestrian crashes of +50% to –27% (Jensen 1999). Bergman et al. (2002) emphasized on the cost-effectiveness of the specific measures, as installation costs may range between US$2,000 and US$20,000, compared to between US$60,000 and US$250,000 for traffic signals. In two lane roads in Melbourne, older pedestrians were found to efficiently select safe traffic gaps and react more quickly to the traffic compared to the crossing behaviour they exhibit in streets without such refuges (Oxley et al. 1997).

3.8. Rural and urban road networks: speed reduction measures

The effectiveness of speed reduction measures for pedestrian safety has been systematically addressed for both young and old road users of all categories (Oxley et al. 1997, Staplin et al. 2001, Haworth et al. 2001, Pucher and Dijkstra, 2003, Pucher and Buehler 2008, 2BESAFE 2012). Literature indicates that countermeasures achieving speed reduction of 0.5 – 18km/h may lead to a decrease of all pedestrian crashes ranging from 17% to 92% (Jensen 1999). In high-activity pedestrian and cyclist areas and there is strong evidence to suggest that even small reductions in vehicle speeds result in substantial reductions in serious injury crashes (Anderson et al., 1997; Oxley et al., 2001). Anderson et al. (1997), using data from Adelaide, South Australia, estimated a 32 percent reduction in pedestrian deaths with 10 percent of collisions being completely avoided with an overall 5 km/h reduction in travelling speed. In urban areas, where most elderly pedestrian crashes occur, they estimated that there would be a 30 percent reduction in fatalities, 14 percent of these crashes would have been completely avoided, and 16 percent of them would have resulted in injuries less severe than death. Reduced speed limits effects are greater in urban areas (Hoareau et al. 2002). Oxley et al. (2001) showed that reduced speed zones, along with other physical measures, such as painted median between tram tracks, coloured crosswalks at intersections and pram crossings lead to estimated reductions of two to three percent in fatal pedestrian crashes and of 15 percent in serious injury pedestrian crashes; these benefits may extend to older pedestrians. Oxley et al. (2004b) review relevant literature and state that the evidence shows that the frequency and severity of crashes increase when speed limits are raised.

3.9. Rural and urban road networks: wider sidewalks

Providing street-narrowing measures (chicanes, slow points, "skinny street," etc.) for the benefit of pedestrian is an effective countermeasure (Campbell et al. 2004). Gitelman et al (2012) summarizes international experience of the effects of different pedestrian safety-related infrastructure measures in relation to i. Accident reduction, i. Conflict reduction, and i. Speed reduction. Gitelman et al (2012) state that providing wider sidewalks along with measures to improve visibility (such as removing obstructions, improving lighting, adding light-reflecting high mounted traffic signs and installing a pedestrian warning system with lights) may significantly reduce conflicts of pedestrians with other vehicles, but also accidents.

3.10. Rural and urban road networks: lighting at crossroads

A review of the effects of lighting at pedestrian crossings showed that the detectability of pedestrian by the drivers were improved when illumination was present (Campbell et al. 2004). Lighting enhanced the awareness of pedestrians related to hazardous situations at crosswalks, for both younger and older drivers. Nambisan et al. (2009) assessed the effectiveness of an automated pedestrian detection device and lighting for midblock crossing. Results show that an increase in pedestrians' observational behaviour and an improvement in motorists' yielding behaviour and positive safety benefits for motorists' and pedestrians' behaviours at the test location. Pedestrian signal indications appear to reduce pedestrian crashes at some intersections, have little or no effect at others, and even increase such crashes at other intersections (Campbell et al. 2004). Retting et al. (2003) reviewed the effects of several traffic engineering measures in pedestrian safety and concluded that the intense lighting at crossing was associated to with significant reductions in nighttime pedestrian crashes.

3.11. Rural and urban road networks: bicycles tracks design characteristics and conspicuity

Using more and wider bicycle tracks in urban roads will decrease accident risk, increase mobility and will provide a feeling of security when travelling in public traffic areas (Oxley et al. 2004) Yet, no effect on safety of older cyclists is documented. Chen et al. (2012), on a before-after study, showed that bicycle crashes were increased after the installation of a bike lane, probably due to the increase in bike demand and the increase in the interactions between bikes and cars at the locations where the dedicated lanes stopped. Extending the cycle path network can have a safety benefit, but only if this does not increase conflicts and crashes at entry and exit points and at intersections (Oxley et al. 2004).

Evidence has shown that drivers feel more comfortable when knowing in which way cyclists are positioned at an intersection when stopped (Herrstedt et al., 1994). Advanced Stop Lines (ASLs) provide a waiting area for cyclists between two stop lines - one for drivers and an ASL for cyclists, so that waiting cyclists are ahead of motor vehicles and can be seen easily (Allsop 1999). Where implemented, ASLs have led to a reduction in accidents involving bicyclists at left turn maneuvers by 35% (Herrstedt 1994, Herrstedt 1997). Separate phasing for cyclists may also lead to a reduction in crashes involving vehicles turning across their line of movement (Allsop 1999). Thomas and De Robertis (2013) review the effects of intersection level treatments for cyclists' safety without placing emphasis to older road users.

Obstacles (e.g. bollards, kerbs, bicycle track narrowing etc.) are critical for the safety of older drivers (Fabriek et al. 2012, Reynolds et al. (2009)). Although no causal relationships may be established, research provide evidence that the low conspicuity of obstacles may significantly affect single-bicycle crashes (Schepers et al. 2014). No specific analyses are conducted for evaluating the specific innervations in relation to older road users safety.

3.12. Rural and urban road networks: bus stop design

A number of best practices covering various aspects of public transport (especially accessibility issues) are implemented at various local, national and EU levels in different countries around Europe followed by directives and guidelines to standardize implementation, yet with increased degree of diversification between countries (GOAL 2013a). To deal with the pedestrians and cyclists safety near transit stops, several countermeasures have been proposed, such improved design of transit stops, special road markings, installation to achieve separation of flows and so on (Oxley t al. 2004b). Fiedler (2007) provides several recommendations related to facilities and bus stops, such as physical strains installations at stops, design solutions to increase orientation and friendliness (e.g. clear signposting), and ensure appearance and functionality of transit vehicles. Other concepts introduced to improve road safety of older transit users include "service routes", a concept aiming to minimize distance to bus stops and remove stressful situations during boarding and alighting and to avoid crowding (Forsberg and Ståhl 1991) and "Flex-route" services, a combination of fixed-route service and demand-responsive, kerb-to-kerb service that are based on advanced booking approaches (Fiedler 2007). Finally, information related measures include clear and legible signs, audibly available information, real-time visual and audio information should also be included at transit stops (OECD 2001). Regardless of the variety of introduced measures, there is limited information available which could be support the effectiveness and economic viability of such solutions.

4. Traffic control at intersections

4.1. Converting permitted to protected left turn

Older drivers have a difficulty in determining the acceptable and safe time gap in order to maneuver through traffic streams when there is no protective phase. Various studies have showed that converted permitted to protected left-turn phases improves left-turn safety because of the decrease in potential conflicts between left-turning and opposing through vehicles (Staplin et al. 2001, Lyon et al. 2005, Srinivasan et al. 2008, 2012). Classen et al. (2007) tested the effectiveness of the FHWA guidelines for intersection design for senior adults and showed that improved intersection without left turn movements significantly improve older drivers' safety. A far more interesting result was that FHWA guidelines for intersection design had similar effect to younger drivers leaving room for plausible policy-making opportunities to cover a wide spectrum of road users. De Pauw et al. (2013) found that left-turn signal control decreases by 37% the number of injury crashes, by 59% the number of severe injury crashes, and has positive effect on left-turn crashes, but no effect on rear-end crashes. The positive effect extends to all road users (car occupants, cyclists, moped riders and motorcyclists). However, Chen et al. (2015) in a study in New York City concluded that the change of permissive left-turn signal phasing to protected/permissive or protected-only signal phasing does not always result in a significant reduction in intersection crashes. Regarding pedestrian safety, the use of exclusive pedestrian signal phase may lead to an improvement in pedestrian crashes up to 68%.

4.2. Optimizing signalization

Many studies have evaluated the effect of different types of upgrading of traffic signals on accidents involving older road users (Shechtman et al. 2007). Installation of signalization at an intersection may lead to a decrease in pedestrian crashes up to 70% (Jensen 1999). Oxley et al. (2004) reported the positive older pedestrians' view on the specific countermeasure, as well as on other electronic installations that extends green and clearance times for pedestrians at intersections. Huang et al. (2000) concluded that safety cones and overhead crosswalk signs appear to be promising tools for enhancing pedestrian safety at mid-block crosswalks on low-speed two-lane roads. Hakkert et al. (2002) underlined that the installation of the warning systems were not related to older pedestrians.

Special attention must be given to elderly pedestrians; most frequently, the calculation of the minimum required time for pedestrians to cross an approach of an intersection in done based on an average pedestrian speed on 1.2 m/sec. Longer and less confusing walk and clearance phases are required for slower walking older pedestrians (Catchpole 1998). Cleven and Blomberg (1998) reported that posting signs at crossing facilities that explained the meaning of the different crossing signals, was effective in lowering crash rates amongst elderly pedestrians over a four-year period. This method of information dissemination was also very visible with 66 percent of survey respondents indicating that they had seen these signs. Chen et al. (2014) in a before-after study showed that an increase to the green time dedicated to pedestrians leads to a decrease in multi-veh, pedestrian, bicycle and injurious and fatal crashes by 47.26%, 28.94%, 41.08% and 41.77%.

5. Route guidance and Signs and Lighting

De Pauw et al. (2014) show that a 5% decrease in the crash rates was achieved after the speed limit restriction, while greater is the gain for serious and fatal accidents. Lee et al. (2006) and Lee and Abdel-Aty (2008) studied the safety benefits of dynamic speed limits (DSL) and used simulated traffic conditions on a freeway in Toronto and marked a reduction of the overall crash potential by 5%-17%. Van Nes et al. (2010) analyzed the effects on the traffic homogeneity, the credibility of the posted speed limits and the acceptance of the different DSL systems. Islam et al. (2013) indicated that the DSLs improve safety by 50%. De Pauw (2015) conducted a before-after study and concluded that DSL systems have positive effect on the number of injury crashes (-18%), mainly due to a decrease in the number of rear-end crashes, but no effect was found on the number of severe crashes. On the joint operation of speed and red light cameras, Vanlaar et al. (2014) found that there were significantly fewer red light running violations after the installation of the cameras compared to before. De Pauw et al. (2014) in a before - after study state that the joint consideration of speed and red light cameras can slightly increase injury crashes, but decreases fatal crashes, severe side crashes and crashes involving cyclists.

In general, a cost -benefit analysis showed that out-of-vehicle ITS applications can reduce average vehicle speeds by between four and eight km/h, whereas the benefit-cost ratio associated with the use of these displays on different road and environment types and found BCRs ranging from 7.7 to around 45, dependent on environment (Corben et al. 2001).

Limited research is dedicated to the effects of improving the traffic signs to drivers, pedestrians, cyclists and PTW safety (Fambro et al. 1997, Hunter et al. 2000, Srinivasan et al. 2008, Government of Victoria, 2009). Elvik et al. (2009) review previous research on sight distance and road accidents and emphasize that there exists conflicting results; increases of sight distance but below 1km lead to increased accident rates, whereas above 1 km there is no statistical significant relationship between accidents and sight distance. However, no clear results are reported for elderly road users. Mace (1988) reviewed sign conspicuity issues related to older drivers and underlines that conspicuity may therefore be aided by multiple or advance signing as well as changes in size, luminance, and placement of signs.

Improved lighting at pedestrian crossing has been found to decrease pedestrian crashes by 30 to 62% (Jensen 1999). In the US, the intersection illumination was associated with the highest benefit-cost ratio (26.8) in reducing fatal and injury crashes (Oxley et al. 2004a). In a variety of tested countermeasures in different US projects, lighting achieved the highest benefit-cost ratio (26.8) related to injuries and crashes (FHWA 1996). A survey on older drivers showed that 70% of the older drivers in the ages of 50 to 97 indicated that more lighting is needed on motorways, especially on interchanges, construction zones and toll plazas (Knoblauch et al. 1997).

6. Concluding Remarks

The present paper presents the findings of an in-depth study on the effectiveness or infrastructure interventions to older road users' safety. Various categories of road users are examined, such as drivers, pedestrians, public transport users, cyclists, and PTW drivers. Literature included both published reports and papers in peer- reviewed journals and international conferences. Among the most interesting results, is that intervention are place elderly at the center of the design. Most measures are designed for typical road users, and their results are further tested on VRUs. The most promising interventions identified include the separation of vulnerable road users from motorized traffic and/or introduction of low design speeds in areas with many vulnerable road users (VRU). Moreover, the development of self-explaining and forgiving roads in urban and rural areas, the reduction of conflicts between VRU's and vehicles and between vehicles at urban intersections, as well as the use of protected-only operations at signalized intersections has been found advantageous. Nevertheless, this effectiveness is rarely based on actual results and experimental findings, as well as a related cost-benefit analysis, which could support the implementation of specific interventions. Further, limited effort has been placed on quantifying the public support to assess whether users are willing to accept specific countermeasures and interventions.

To this end, the findings point towards the need to deliver a novel manner to think of infrastructure interventions to improve road safety in a more age-friendly urban and rural environment. Infrastructure interventions should always be considered in a framework of comprehensive safety interventions that will include educational and training, licensing and enforcement interventions, as well as the integration of advanced technologies, especially those that are included in modern vehicles. Infrastructural interventions, education & training initiatives, licensing restrictions and vehicle & ITS technologies can only compensate for reduced fitness to drive to a certain degree. Therefore, a key policy priority the (near) future would be the development of the proper mix of interventions that will enable people lifelong mobility.

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