How is Older Drivers Safety enhanced by In-Vehicle Assistance Systems?

Eleni Vlahogianni[1], Eleonora Papadimitriou[1], George Yannis[1], Franck Leopold[2], Evelien Polders[3], Tom Brijs[3], Concetta Durso[4], Konstandinos Diamandouros[4]

[1] National Technical University of Athens, Athens, Greece
[2] Laboratory of Accidentology, Biomechanics and Human Behaviour (LAB), France
2 IMOB – Hasselt University, Belgium
4 European Road Federation, Brussels, Belgium

ABSTRACT

Older adults comprise the fastest growing part of the population worldwide, an issue with far reaching implications to mobility and road safety. Interactions between the vehicle and Intelligent Transportation Systems (ITS), communication systems and technologies for continuously collecting data on drivers' behavior may enhance the safety of elderly road users. The present paper reviews existing literature dedicated to the effectiveness of in-vehicle ITS to older drivers' safety. Emphasis is given to the intersection control, the lateral/longitudinal control, as well as the parking, the night vision and the general navigation. Finally, some future research directions focused on elderly safety and in-vehicle ITS are discussed.

Keywords: elderly, road safety, ITS, in-vehicle technologies

1. INTRODUCTION

By 2050, more than 147 million people aged 65 or over will be living in the European Union. This is a substantial increase compared to the 92 million in this age group in 2013 (Eurostat, 2015). In the US, it is projected that by 2060, the Americans aged 65 and over will be more than doubled, reaching the 24% of the population (Mather et al. 2015). Due to the demographic changes in the future, more elderly will actively participate in traffic making road safety in the forefront of research interest.

Interventions within the area of vehicle and Intelligent Transportation Systems (ITS) provide potential to enhance the safety of elderly road users since advanced vehicle technologies or driver assistance systems can help the elderly to stay mobile in a safe way by assisting them to compensate for their age-related functional declines. Rakotonirainy et al. (2009) state that ITS efficiency is linked to the motor (e.g. range of motion, dexterity, coordination, reaction time), physiological (e.g. visual, hearing) and cognitive abilities (e.g. divided/selective/sustained attention, tracking, memory, perception) of road users. Currently, these technologies are developed without applying a user-centered approach for older drivers. Applying a user-centred approach for older drivers to the design of in-vehicle ITS can be beneficial for the rest of road users as the design of in-vehicle Intelligent Transportation Systems that take the special needs of for elderly drivers into consideration leads to (Pauzie 2002): i. the simplification of the driving task and reduces performance differences between old and young drivers; and ii. the optimization of on-board systems (better legibility and intelligibility of the information, simplified dialogue). Vrkljan and Miller-Polgar (2005) have discussed the benefits of incorporating "universal design" principles and human factors engineering in the development of this technology. Nevertheless, limited are the studies that provide solid evidence for the effectiveness and cost benefit of in-vehicle technologies dedicated to older drivers.

The scope of the paper is to review the existing literature dedicated to in-vehicle ITS for elderly with emphasis on the diversity of such systems, their effectiveness in relation to the cost for deployment and the benefits that are attained by implementing them. The paper is structured as follows: the next section presents the main in-vehicle technologies that are available with emphasis on intersection level control, lateral/longitudinal control, parking, night vision and general navigation. The following section reviews the findings from studies that have evaluated the deployment of in-vehicle ITS dedicated to older drivers. Next, some challenges faced on a conceptual and implementation level related to older driver in-vehicle ITS are discussed followed by a conclusion section.

2. IN-VEHICLE INTELLIGENT TRANSPORTATION SAFETY SYSTEMS

The literature review was conducted in a structured manner to critically discuss literature in relation to ITS safety related ADAS solutions dedicated to monitoring and driving assistance, the protection and support, transit and to visibility/lighting in terms of the capacity (Motor / Physical conditions, Sensory, cognitive etc), the limits of the system, the type of user (driver, rider, pedestrian) and the degree of dedication to elderly safety (scale 1 to 3). Further, the review summarized the existing ADAS systems (for passenger cars and powered two wheelers) literature and the associated findings in relation to the type of assistance (road user, vehicle, infrastructure), the conditions (pre, during or post-crash), the type of user (drive, passenger pedestrian) and the type of effect (exposure, accident risk, injury risk) (Tables 1-4). Moreover, the literature was systematically analyzed based on the following safety related ADAS categories: i. at intersections, ii. Headway control, iii. Curve control, iii. Navigation, and iv. Night driving.

Table 1: ITS safety related ADAS solutions dedicated to monitoring and driving assistance.

Capacity	Designation	Limits	User*	Dedication to elderly **
Cognitive	Drowsy Driver Detection System / Impairment Warning / Driver Alert Control	Needs driver action	D	2
	Adaptive Cruise Control	Adverse weather	D	1
	Cruise control	-	D	1
	Curve Speed Warning System	accuracy of digitized maps	D	2
	Speed limiter	No particular limits	D	1
	Traffic Impediment Warning System	No particular limits	D	1
	Overtaking Assistant	Adverse weather / reduced visibility	R/D	1
	Curve speed warning system	Accuracy of digitized maps	R	1
	In-pavement lighting systems	Not defined	P/D	1
	Drowsy Driver Detection System / Impairment Warning / Driver Alert Control	Needs driver action	D	2
Cognitive/ motor	Low speed following	-	D	1
	Head-Up Display	Limited information	D/P	1
Cognitive/sensory	Forward Collision Warning System	Reliance on sound	D	2
	Lane Departure Warning	Adverse weather / reduced visibility	D	2
	Lane Change Assistant	Adverse weather / reduced visibility	R/D	2
	Adaptive Cruise Control	Adverse weather	R	1
	Advanced Rider Assistance Systems	Not yet known	R	1
	Blind spot monitor	Not yet known	R	2
	Collision warning system	Reliance on sound	R	1
	Emergency brake assistance	No particular limits	R	2

	Intelligent speed adaptation	GPS accuracy	R	1
	Lane keeping assistant	Adverse weather / reduced visibility	R	2
Motor	Biometric vehicle (the car that cares)	Not defined	D	2
	Deflation Detection System	Accuracy issues	D	1
	Emergency Brake Assist Dynamic Brake Control	Requires action of the driver	D	2
	Full speed range adaptive cruise control	Adverse weather	D	1
	Hill Start Assist, Auto Hold, Hill Assist	No particular limits	D	2
	Lane Keeping Assistant Lane Keeping System	Applicable to high speeds	D	2
	Tyre Pressure Monitoring System	User involvement	D	1
	Biometric vehicle (car that cares)	Not defined	D	2
Motor / Physical conditions	Electrical assisted bicycles	No particular limits	R	2
	Run-on-flat tyre	Not repairable	D	2
	Combined Braking System	No particular limits	R	1
	Motorcycle Anti-lock braking systems	need training	R	1
	Traction control system	Adverse weather	R	1
	Vacuum servo (brake booster)	No particular limits	R	1
Motor cognitive	Electronic Stability Control	Adverse weather	D	1
Motor Sensory	Blind Spot Monitoring System/Blind Spot Information System/Blind Spot Intervention/Passive Blind Spot Monitoring	Adverse weather / reduced visibility	R/D	2
Motor Sensory cognitive	Automatic Park assist	No smartphone use	D	1
	Park assist	Accuracy issues	D	2
	Advanced Emergency Braking System Automatic Emergency Braking Collision Avoidance Forward Collision Mitigation Predictive Emergency Braking System	Adverse weather	All	2
	Advanced Emergency Braking Pedestrian	Adverse weather	D	2
Sensory	Bicycle braking light	No particular limits	R	1
	Low Friction Detection	-	D	1
	Manoeuvring Aids for Low Speed Operation	-	D	2
	Speed Sign Recognition	Adverse weather/lighting/ infrastructure conditions	D	2
	Traffic Sign Recognition	Adverse weather/lighting/ infrastructure conditions	D	2
	Active pedestrian protection system	Accuracy issues	D/P	2
	Night/black panel	-	D/P	2
	Helmet-Mounted Displays	No particular limits	R	1
	Rear-view Displays	Drivers distraction	R	1
	Tyre pressure control system	User involvement	R	1

**D: driver, R: rider, P: pedestrian*
***low 1 - high 3*

Table 2: ITS safety related ADAS solutions dedicated to protection and support.

Capacity	Designation	Limits	User*	Dedication to elderly **
cognitive	Seat belt reminder	A buckle can be fastened and the passenger not attached	D/P	1
	eCall (Automatic crash notification) (for cars)	wireless telephone network coverage existence	All	1
	eCall (Automatic crash notification) (for motorbikes)	wireless telephone network coverage existence	All	1
Motor / Physical conditions	Safety helmet	Limited to low speed impact	R	1
	Active bonnet	Activation speed depending on the size of the pedestrian	R/P	1
	Airbag helmet	Limited to low speed impact	R/P	1
	Airbag Pedestrian Protection	Efficiency issues	R/P	1
	Collapsible steering column	No wearing of the seat belt	D	1
	Pedal Release System	-	D	1
	Active Head restraint	Strong dependencies from seat belt wearing, adjustment and collision intensity	D/P	1

Anti-submarining airbag	-	D/P	1
Anti-submarining device	-	D/P	1
Anti-Whiplash Seat	Stature of the occupant	D/P	1
Curtain Airbag Inflatable curtain	Size of the occupant	D/P	1
Frontal airbag	No wearing of the seat belt	D/P	1
Knee airbag	No wearing of the seat belt	D/P	1
Pre-crash occupant preventive measures Systems (e.g. Presafe, Pre Sense)	Depends on driver actions	D/P	1
Pre-tensioner	Use of a belt clip	D/P	2
Safety belt and Belt Force limiter	Use of a belt clip	D/P	3
Side head/thorax airbag	Occupant's size. Seat back cover poorly mounted	D/P	1
Side thorax airbag	Occupant's size. Seat back cover poorly mounted	D/P	1
Side thorax/abdomen airbag	Occupant's size. Seat back cover poorly mounted	D/P	1
Airbag jacket	Limited to low speed impact	R	1

**D: driver, R: rider, P: pedestrian*
***low 1 - high 3*

Table 3: ITS safety related ADAS solutions dedicated to transit.

capacity	Designation	Limits	User*	Dedication to elderly **
Motor / Physical conditions	Low-floor buses	Illegal parking	B	3
Sensory	Bus stop display system	user with a poor vision	B	1
Sensory	Hand-held communication system(bus/passenger)	user with a poor vision	B	1
Sensory	Service display at bus stop Audio announcement by bus	Users with hearing disabilities	B	2
Motor / Physical conditions	Smart payment card	Not applicable to users not owning a card	B	2

**D: driver, R: rider, P: pedestrian, B: bus users*
***low 1 - high 3*

Table 4: ITS safety related ADAS solutions dedicated to visibility/lighting.

Concerned capacity	Designation	Limits of the system	Targeted user category	Dedication to elderly *
Cognitive	Automated Headlights	Adverse weather	Driver	1
Cognitive/sensory	Automatic full light	Adverse weather	Driver	1
Cognitive/sensory	Advanced front-lighting system	No particular limits	Riders	1
Sensory	Speed Vest	No particular limits	Cyclist	1
Sensory	Night Vision (for cars)	Adverse weather	Cyclist and pedestrian	2
Sensory	Bending light	Adverse weather	Driver	1
Sensory	Cornering light	Efficiency related to speed	Driver	1
Sensory	Headlamp levelling	Glare has to be obvious	Driver	1
Sensory	Night vision (for motorbikes)	Adverse weather	Riders	2
Sensory (pedestrian perception)	Daytime Running Lights	No particular limits	Driver and pedestrian	1
Sensory cognitive	Adaptive Front Light System	Could glare opposite road users	Driver	1

**low 1 - high 3*

3. THE WAY FORWARD

In-vehicle ITS and safety are continuously being revolutionized by the advances in technology and communications. Today, two main research fields emerge which form a significant challenge for both research community and industry in relation to elderly road safety. These are discussed in the following sections.

3.1 Driver monitoring

Driver monitoring may provide two types of technological approaches. The first one are autonomous ADAS systems to assess specific drivers' states and to warn them of the criticality of these states (Boverie et al. 2008). Typical example of these devices are Driver Drowsiness/ Sleeping Monitoring Systems, aiming to diagnose drivers' low vigilance states in real-time and to display this information to them or to take control over the car.

The second approach is to design embedded diagnosis functions to monitor the driver and to provide real-time diagnosis towards all other types of driving aids, to activate these aids when required and / or to adapt Human-Machine Interactions modalities according to the specific status of the driver and/or the situational context (Engström et al. 2006, Bellet and Manzano 2007, Amditis et al. 2010). The aim is to design Human-Machine Interaction managers able to observe car drivers, to diagnose driving errors, inadequate behaviors, non-voluntary risk taking, or all other critical consequences of erroneous Situation Awareness of the driver due to misperceptions or misunderstandings of the traffic situation.

While this type of ADAS can provide valuable assistance for the elderly, especially for those with cognitive or driving impairments, it is a technology that is developing less quickly due to the lack of relevant data. Until recently, elderly special abilities to drive have been assessed using on-road tests or driving simulators, which may provide unrealistic results. With the increasing use of advanced data collection approaches (for example On Board Diagnostics, smartphone, smartwatch technology and location based services) to unobtrusively collect big data related to driving that have already penetrated the transportation sector and are being systematically used to assess mobility and – if possible - driving risk (Vlahogianni 2015, Tselentis et al. 2016), continuous and resourceful information on the interactions between vehicles and elderly drivers will be available to be used to improve elderly safety. This information will be critical to the construction of efficient in-vehicle ITS systems for all age ranges.

3.2 Autonomous and Connected Vehicles

The concepts of self-driving cars or autonomous vehicles are progressing in an unprecedented pace. The major players in the automotive industry agree that the mobility of tomorrow will inevitably come with the autonomous vehicle. Car manufacturers have for long focused on the realization on this concept. The autonomous vehicle can be considered as the ultimate ADAS, which will allow drivers to travel safely and efficiently.

Autonomous vehicles will appear in several steps: The first one is to combine ACC Stop&Go with Lane Centering Assist, resulting in partially automated driving at low speeds and in specific areas (the driver still monitors and takes over when necessary). A second possible step is the Platooning: a first vehicle is driven by a driver (typically a professional driver in a truck) and several vehicles follow in a highly automatic mode (no monitoring by the driver, but he takes over to change paths, exit the highway etc). The last step is the full autonomous driving with all the driving tasks automated: navigation, vehicle control, and parking. It will regroup all other intelligent transport systems.

Several studies have already examined the autonomous vehicle technical development process (Wallace and Silberg, 2012, Litman, 2015). In the "Autonomous vehicle implementation prediction" study, the scope for this ultimate ADAS shows only modest impacts on transportation planning factors such as road and parking supply and public transit demand for the next few decades (Litman, 2015). This is mainly explained by the fact that, it will probably be 2050 before a middle-income family can afford to buy an autonomous vehicle. An additional cost of 3000€ could be expected for this technology compared with a classic vehicle. Beside this, the autonomous vehicle encounters a high public support even if some people stay suspicious regarding the hacking risk or electronic failure.

According to a U.S. Department of Transportation (DOT) report, combined V2V and V2I systems may potentially address about 81 percent of all-vehicle target crashes, 83 percent of all light-vehicle target crashes, and 72 percent of all heavy-truck target crashes annually (Najm et al. 2010). Nevertheless, Yang and Couglin (2014) emphasize the need to tackle the critical issue of the interaction of autonomous technologies with an older driver population and discuss the advantages and challenges faced by aging drivers with reference to in-vehicle technology for self-driving cars based on recent research findings.

3.3 Raising Awareness of elderly for in-vehicle ITS

A recent study based on a comparative assessment of both interview data and field data showed that the manner the participants themselves described their need of support differed from what support they requested (drivers) and gave (co-drivers) in real driving (Mårdh 2016). The same study revealed areas in which older drivers need and request support. To this end, understanding older drivers' perception of in-vehicle devices will allow experts to take the necessary steps to ensure their smoother acceptance and complete success of their deployment. A European study has showed that older drivers are, in general, more supportive of the considered in-vehicle technologies, while female respondents also show a higher willingness to adopt (Yannis et al. 2010). Recently, Rhiu et al. (2015) reviewed a series of published papers on human–vehicle interaction studies focused on elderly drivers and concluded that research should focus on personalized services, as well as new technology and levels of automation acceptance to develop and improve smart cars in the future.

5. CONCLUSIONS

Interventions within the area of vehicle and ITS technologies and communications for collecting continuously data on drivers' behavior provide potential to enhance the safety of elderly road users. The present paper attempted to review existing literature on the effectiveness of in vehicle ITS to elderly safety. From the analysis, it is evident that, although a variety of different ITS strategies exists, these technologies are developed without applying a user-centered approach for older drivers. Advanced in-vehicle technologies or driver assistance systems can help the elderly to stay mobile in a safe way by assisting them to compensate for their age-related functional declines. Moreover, findings also show that several "hot" research areas, such as driver's monitoring and autonomous vehicles, still neglect the importance of designing for elderly as well.

Towards the direction of developing age-friendly vehicles and driving conditions, several issues need to be considered. To start, it is of importance to include elderly and more vulnerable users to the design of active safety standards. Moreover, introducing a standardized testing procedure to systematically assess the usability and effectiveness of advanced vehicle technologies for older drivers through EuroNCAP procedures will ensure the "design for all" aspect of in-vehicle ITS applications, especially those that is considered the most critical for road safety, namely crash avoidance systems, such as intersection and lane change assistants and active pedestrian protection systems. Further, education and training older road users on the correct usage of active safety technologies (elderly-adapted ADAS technologies) will be beneficial to both the efficiency and the acceptance of such systems. Finally, automated or semi-automated driving should be also explored as a means to extend the driving life of older road users by offering assistance to compensate for functional limitations.

REFERENCES

Amditis, A., Pagle, K., Joshi, S., & Bekiaris, E. (2010). Driver–Vehicle–Environment monitoring for on-board driver support systems: Lessons learned from design and implementation. *Applied Ergonomics*, *41*(2), 225–235.

Bellet, T., & Manzano, J. (2007). To be available or not, that is the question: a pragmatic approach to avoid drivers overload and manage in-vehicle information. (Vol. ESV Paper n° 07–0434). Presented at the 20th Enhanced Safety of Vehicles Conference (ESV 2007), Lyon, France.

Boverie, S., Giralt, A., & Le Quellec, J. M. (2008). Diagnostic Fusion for in Vehicle Driver Vigilance Assessment. In *Proceedings of the 17th World Congress of the International Federation of Automatic Control (IFAC'08)* (pp. 12825–12830).

Engström, J., Arfwidsson, J., Amditis, A., Andreone, L., Bengler, K., Cacciabue, P. C., Nathan, F. (2006). Towards the Automotive HMI of the Future: Mid-Term Results of the AIDE Project. In D. J. Valldorf & D. W. Gessner (Eds.), *Advanced Microsystems for Automotive Applications 2006* (pp. 379–405). Springer Berlin Heidelberg.

Eurostat. (2015). Population projections: Main scenario - Population on 1st January by sex and single year age. Retrieved from http://ec.europa.eu/eurostat/data/database.

Litman, T. (2015). Autonomous Vehicle Implementation Predictions: Implications for Transport Planning. Presented at the Transportation Research Board 94th Annual Meeting. Retrieved from http://trid.trb.org/view.aspx?id=1338043.

Mårdh, S. (2016). Identifying factors for traffic safety support in older drivers. Transportation Research Part F: Traffic Psychology and Behaviour, 38, 118-126.

Mather M., L. A. Jacobsen, and K. M. Pollard, "Aging in the United States," Population Bulletin 70, no. 2 (2015).

Mather M., L. A. Jacobsen, and K. M. Pollard, "Aging in the United States," Population Bulletin 70, no. 2 (2015).

Rakotonirainy, Andry and Steinhardt, Dale A. (2009) In-vehicle technology functional requirements for older drivers. In: Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications, 21 - 22 September 2009

Rhiu, I., Kwon, S., Bahn, S., Yun, M. H., & Yu, W. (2015). Research Issues in Smart Vehicles and Elderly Drivers: A Literature Review. International Journal of Human-Computer Interaction, 31(10), 635-666.

Tselentis, D. I., Yannis, G., & Vlahogianni, E. I. (2017). Innovative motor insurance schemes: A review of current practices and emerging challenges. Accident Analysis & Prevention, 98, 139-148.

Vlahogianni, E. I. (2015). Computational Intelligence and Optimization for Transportation Big Data: Challenges and Opportunities. In Engineering and Applied Sciences Optimization (pp. 107-128). Springer International Publishing.

Vrkljan, B., & Miller-Polgar, J. (2005). Advancements in vehicular technology: Potential implications for the older driver. International Journal of Vehicle Information and Communication Systems, 1(1/2), 88-103

Wallace, R., & Silberg, G. (2012). Self-driving cars: The next revolution. Centre for Automotive Research, Transportation Systems Analysis Group.

Yang J and Couglin J F (2014) In-vehicle technology for self-driving cars: Advantages and challenges for aging drivers, International Journal of Automotive Technology (Impact Factor: 0.97). 03/2014; 15(2):333-340.

Yannis, G., Antoniou, C., Vardaki, S., and Kanellaidis, G. (2010). Older Drivers' Perception and Acceptance of In-Vehicle Devices for Traffic Safety and Traffic Efficiency. J. Transp. Eng., 10.1061/(ASCE)TE.1943-5436.0000063, 472-479.