In-vehicle Technology Functional Requirements for Older Drivers

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ABSTRACT
Older drivers represent the fastest growing segment of the road user population. Cognitive and physiological capabilities diminishes with ages. The design of future in-vehicle interfaces have to take into account older drivers' needs and capabilities. Older drivers have different capabilities which impact on their driving patterns and subsequently on road crash patterns. New in-vehicle technology could improve safety, comfort and maintain elderly people's mobility for longer. Existing research has focused on the ergonomic and Human Machine Interface (HMI) aspects of in-vehicle technology to assist the elderly. However there is a lack of comprehensive research on identifying the most relevant technology and associated functionalities that could improve older drivers' road safety. To identify future research priorities for older drivers, this paper presents: (*i*) a review of age related functional impairments, (*ii*) a brief description of some key characteristics of older driver crashes and (*iii*) a conceptualisation of the most relevant technology interventions based on traffic psychology theory and crash data.

Categories and Subject Descriptors
D.m [**Software**]: Miscellaneous; D.0 [**General**]

General Terms
Human factors

Keywords
ADAS,ITS

1. INTRODUCTION
Driving plays an important role in older drivers' mobility as 90% of older drivers rely on a private car as their primary mode of transport [19]. Driving cessation can thus significantly reduce older driver's mobility. Driving cessation is associated with significant negative health consequences such feelings of depression and social isolation.

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In North America the proportion of the population over 65 years is expected to double by 2030 [14]. Similarly, the proportion of Australian licensed drivers aged over 65 is predicted to increase from 13 % in 2000 to 22 % in 2030. Of drivers aged over 65 years holding a licence, current research has found 96% report to be active drivers [42]. Older drivers aged over 65 are the most rapidly growing segment of road users in Australia in terms of number of drivers licensed, distance driven, and proportion of the driving population [16]. The ratio of retirees to workers in Europe is estimated to double to 54% by 2050 from four workers to two workers for every retiree [5]. It has been estimated that the working age population in the European Union will decrease by 48 million between 2010 and 2050 (-16%), while the elderly population will increase by 58 million, an increase of 77% [44].

The growing number of older drivers and the significance of the problem that they are facing to maintain their mobility for longer has generated siginificant research interest. Older drivers have low rates of crash per head of population, however their fatal crash rate per mile travelled increases starting at 70 years. This is largely attributable to increased frailty, particularly chest injuries and medical complications rather than over representation in crashes [18].

Ubiquitous/pervasive computing technology such as sensors, actuators, wireless networks and processors are commonly used to assist humans to perform various tasks. Context-awaren systems have become a growing area of study for pervasive and ubiquitous research communities. Unfortunately context-aware systems have not been thoroughly used to assist driving tasks. Technology based interventions such as Advanced Driving Assistance Systems (ADAS) have been hailed as a potential solution to improve road safety including older driver safety. It has been estimated that ITS could reduce fatalities and injuries by 40% across the OECD, saving over USD 270 billion per year [17]. Intelligent Transport Systems (ITS) and Advanced Driver Assistance Systems (ADAS) are growing research fields that use new technology aimed at improving road safety.

Computing assistance can improve situational awareness and reduce older driver errors. Although context-aware systems have great potential to save lives and prevent injuries on the road, they have not yet been integrated to safety critical applications for older drivers. With existing high demands on a driver's visual attention, many ADAS have been designed with a HMI that simplifies driver interactions with the view to reduce cognitive or visual demands. Speech based or tactile interfaces have been designed to reduce the effect of distraction [34].

However, scientific data is still lacking on the design and effectiveness of ADAS interventions, making it difficult to implement relevant policies as to their best use. The design of an ADAS intervention to improve older driver safety necessitates a clear understanding of the context in which crashes occur and the context in which it can assist. To address these concerns, this paper presents (*i*) an overview of age related driving impairments (*ii*) data analysis of road crashes involving older drivers to identify risk factors (*iii*) a review of relevant psychology theories to assess their suitability and effectiveness of in-vehicle technology to remediate identified crash patterns, and (*iv*) a discussion on the adequacy of existing technology to assess older drivers. Finally, recommendations regarding future research to improve older drivers safety are given.

2. OLDER DRIVERS' FUNCTIONAL IMPAIRMENTS

Driving is a complex task which requires cognitive and motor coordination to react and adapt behaviour to changing situations. It is widely recognised that older drivers suffer from age-related impairments to motor, sensory and cognitive abilities. Issues cited in past research include reduced mobility, reduced flexibility, reduced range of motion, slower reaction times [9], reduced visual acuity, prolonged visual accommodation and adaptation times, reduced peripheral vision, increased glare sensitivity [10], reduced ability to deal with high cognitive load driving tasks [29] and greater susceptibility to distraction [7]. Studies on closed roads have suggested that elderly drivers have slower reaction times, less accurate car following pattern and poorer merging behaviour at junctions than young drivers [45].

In studies related to the use of navigation systems by older drivers, [3] and [12] reported that older drivers had difficulty with the dual task of following a route guidance system while driving. Distraction caused by such systems may thus differentially affect older drivers negatively. Older drivers have been shown to spend significantly more time looking at navigation displays than younger drivers [28] [8].

Analysis of elderly drivers has shown that a battery of tests covering attentional, perceptual, cognitive and psychomotor performance are all significantly correlated with unsafe driving incidents as reported by police, family members and licensing agencies[21]. These tests specifically included selective and divided attention, field dependence, short term memory, digit matching, and simple reaction time. Visual tests of acuity were not as strongly correlated with unsafe driving incidents in this instance while psychomotor and cognitive skills were most highly correlated. While research has often defined an older person as those older than a specific chronological age, it is often of more relevance to consider age-related changes in physical, psychological and cognitive ability as a marker of when someone should be classed as an "older driver" [13]. It should also be noted that functional limitations and age related disorders do not necessarily lead to unsafe driving behaviour if a driver can self-regulate by avoiding complex driving situations such as night driving or intersections [23].

This suggests that there is no unique intervention that can uniformly help older drivers as a group. Intervention should be aware of limitations of a given driver with the view to assist him or her.

3. OLDER DRIVERS ROAD CRASH PATTERN

Several studies have identified factors contributing to older drivers crashes in driving simulators and on roads. The analysis of on-road crash involving elderly has shown that they are different from those of the overall driving population. This section presents the crash data analysis results of the Australian state of Queensland to identify the circumstances and contributing factors to crashes which are specific to older drivers.

3.1 Road crash database

The analysis was conducted using data from Queensland Transport's road crash database [41]. The road crash database is an electronic record of police-attended or otherwise reported road crashes that contains considerable information regarding the crash including the date, time, factors contributing to the crash and road characteristics. The level of analysis for this paper was the number of units (vehicles, excluding pedestrians) involved in crashes between 2000 and the end of 2004. Results from serious casualty crashes (those crashes resulting in a fatality of hospitalisation) are presented to exclude the large number of minor incidents. This analysis thus took into account 31,370 vehicles involved in crashes during this time period.

This database has a number of limitations that should be taken into account when interpreting the results. The crashes represent only those that are police reported - though this is likely to be the case for a large majority of serious crashes. The analyses in this paper consider three older age groups of 60 to 74 years, 75-79 years and those aged greater than 80 years, along with a broad younger comparison sample of drivers aged 17-59 years. These age groups were chosen to correspond with the ages at which restrictions begin to be placed on older drivers within Australia.

3.2 Results of road crash analysis

Table 1 shows the number of units (vehicles involved in crashes) broken by age group of the vehicle controller and the traffic features present at the site of the crash. Older drivers aged 60 and above were over-represented at a statistically higher level in crashes involving all forms of traffic control, with the proportion of crashes involving traffic control increasing steadily as age increased. This pattern also applies to those traffic scenarios involving give way or stop signs. There was however no significant difference between the age groups in terms of the proportion of crashes at controlled traffic lights, though a small trend for greater representation in the older age groups was present.

Table 2 presents the contributing factors of serious casualty crashes by age group. As before, statistically significant

Table 1: Queensland Serious Casualty Crash Units, 2000-2004, by Age Group and Traffic Control

	Age Group				
Variable	17-59	60-74	75-79	80+	Sign.a
Any Traffic Control	(n=31,370) 29.2%	(n=2,937) 35.6%	(n=612) 42.5%	(n=538) 44.1%	p< .001
Give Way Sign	(n=31,370) 9.2%	(n=2,937) 12.4%	(n=612) 14.2%	(n=538) 16.0%	p< .001
Operating Traffic Light	(n=31,370) 15.0%	(n=2,937) 15.6%	(n=612) 17.8%	(n=538) 17.7%	ns
Stop Sign	(n=31,370) 4.0%	(n=2,937) 6.2%	(n=612) 8.5%	(n=538) 8.9%	p< .001

crash distributions were found for a number of key crash circumstances, namely alcohol, fatigue, speeding and failure to give way; with no differences found between the age groups in terms of distraction. The involvement of illegal risk taking behaviours such as speeding and alcohol showed a substantial drop from the younger age group to the three older age groups. The involvement of fatigue showed a steady and significant decline as the age group increased in years, though this proportion was small across all age groups. Corresponding to this finding, the proportion of crashes occurring in the nighttime showed a marked decrease for the older age groups as compared to the 17-59 group.

Of particular note however was the overrepresentation of older drivers in Failure to Give Way crashes. This type of driving error is commonly made by senior drivers. Crashes involving age groups over 60 years of age were between 2 and 3.8 times more likely to involve a failure to give way than the 17-59 years age group. The proportion of such crashes showed a notable increase from the 17-59 years age group to the 60-74 years age group, as well as between the 60-74 and 75-79 years age groups.

Our results conform with existing research findings stating that older drivers are more likely to crash at intersections and other complex traffic situations [29] [20].

4. DRIVING BEHAVIOUR THEORIES

Drivers operate in highly dynamic contexts. Driving is a complex, continuous, multitask processing that involves driver's cognition, perception and motor movements. Section 3 showed that complex driving situations increase the likelihood of older driver's errors during decision making. Context-aware systems for cars are one method to provide a greater awareness of relevant information about the driving situation in order to assist the driver in the decision making process.

In-vehicle context aware systems aim to take into account more contextual information related to the driving task in order to produce adapted or customized actions. Driving tasks are classified into two categories, both of which can be assisted by a context-aware system:

- Primary task: Tasks restricted to longitudinal/lateral vehicle control and vigilance.
- Secondary task: Other tasks that do not require continual performance.

Driving a car requires a balanced and dynamic allocation of attention between the primary and secondary driving tasks. Performing the primary and secondary tasks are part of driving behaviour and involve decision makings followed by actions.

Theoretical models abound in literature as a means to explain and predict driver behaviour. Existing driver behaviour models are largely subjective and based on self-report scales [30]. They strongly emphasize the driver's cognitive state and have incorporated important behavioral concepts such as motivation, task capability [11], belief (theory of planned behavior) [1] or risk assessment. However, motivational models such as risk compensation [43], risk threshold [25] or risk avoidance remain highly subjective concepts. Subjective risks have been identified as a core concept influencing decision making [43] [31]. However [25] rejects such concepts and argues that the driving task is about maintaining a safety margin. Fuller [11] models driver's decision making as an interface between task difficulty and driver's capability. A useful model which is able to bring together a number of these concepts is that of the Michon Model.

Michon has defined a model to express the cognitive process of driver decision making [24]. This model allows quantitative measurement and covers some concepts covered in functional models. Each level of the model corresponds to a decision making level requiring a different type of information. Michon's model corresponds roughly to the information processing model defined by [31] whose hierarchical model describes three levels of information characterized by their degree of complexity. These are namely knowledge, rule based and skill based. The three levels defined by Michon are strategic, tactical and operational [24]:

- The strategic level is the highest level where general goals such as route choice, navigation and timing are set. Driving plans are formed and modified, goals established, prioritized, re-prioritized and satisfied or forgotten in real time as the driver assesses different factors from the environment, driving and vehicle. Expectancies and preferences are also part of this level.
- The tactical level involves decision making related to the management of current driving activity such as maneouvering. Tactical actions follow a pattern specific

Table 2: Queensland Serious Casualty Crash Units, 2000-2004, by Age Group and Contributing Factors to Crashes

	Age Group				
Variable	17-59	60-74	75-79	80+	Sign.a
Alcohol	(n=31,370) 10.4	(n=2,937) 3.7	(n=612) 3.9	(n=538) 1.9	p< .001
Fatigue	(n=31,370) 5.2	(n=2,937) 4.3	(n=612) 4.6	(n=538) 3.5	p< .001
Speeding	(n=31,370) 4.9	(n=2,937) 0.5	(n=612) 0.2	(n=538) 0.7	p< .001
Failure to Give Way	(n=31,370) 6.7	(n=2,937) 13.7	(n=612) 21.2	(n=538) 25.1	p< .001
Distraction	(n=31,370) 0.2	(n=2,937) 0.1	(n=612) 0.2	(n=538) 0.3	non-sig
Time of Day Day (6:00am - 5:59pm) Night (6:00pm - 5:59am)	(n=31,370) 70.4 29.6	(n=2,937) 85.9 14.1	(n=612) 91.2 8.8	(n=538) 92.2 7.8	p< .001

to drivers and can be assimilated to a profile. For example, the following distance chosen to remain behind another vehicle is determined by each driver's profile (e.g. aggressivity).

- The operational level involves vehicle handling or executive actions which implement the maneouvers decided at the tactical level. This level is performed almost without conscious thought. The result of such actions are directly measurable as vehicle dynamics.

Augmenting drivers situational awareness can operate at the strategic, tactical or operational level. The effectiveness of technological interventions at each level of Michon's decision making hierarchy is not well documented. However, it is well accepted that technological intervention could have dual opposite effects such as:

- making the driver aware of critical safety information well ahead and providing the driver with enough time to react safely.
- distracting the driver from the main critical driving task by overwhelming the driver with irrelevant, inaccurate or confusing information.

Context-aware systems often assume that users have the cognitive abilities to acquire the produced context-aware information. Such assumptions may be valid in desktop environments but are fundamentally inadequate and potentially unsafe in driving conditions. Conveyed awareness information requires driver's attention in order to register it. Registering information cognitively is not an effortless task.

5. DISCUSSIONS AND POTENTIAL TECHNOLOGY

In the US, approximatively 50% of all traffic crashes and 50% of injury crashes occur at intersections and 27% of intersection fatalities involved people 65 years of age or older (FHWA,08). The current data from the Queensland region is in line with a number of previous findings in that complex road environments are highly represented in crashes, with the older age groups of 75 years of age or older showing a marked increase in proportional crash involvement at crossroad intersections and where "failure to give way" was a contributing factor. Any ITS technology which could reduce the complexity and demands of such driving tasks could thus potentially improve older driver safety.

For ITS and especially in-vehicle technology to be effective, its operational/functional demand must be compatible with 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. This is particularly relevant to the growing driver population of older drivers. Existing technologies can provide such functionalities. Functionalities is about what the device does and what does it perform. The previous sections identified the functional needs in terms of contributing factors to crashes and older drivers functional impairments. The identified functionalities to be provided to the driver could be presented in different HMI forms. The design and the ergonomy of such technology are very important however this discussion focuses on the functional requirements.

An assistive device facilitates drivers task performance by providing real time advice, instruction, warning or even by taking control of the vehicle's dynamics. They operate in advisory, semi-automatic or fully automatic modes. The advisory and semi-automatic modes require human interventions with the associated human computer interface. An ITS intervention demanding a significant level of attention or motor activity (e.g neck torsion) from older drivers would not enhance older drivers safety. Additional advisory cues could also confuse the driver as older adults have difficulty in tasks that involve suppressing or inhibiting the influence of irrelevant information [46].

Older drivers are more likely than younger drivers to be at fault in crashes typically because they failed to yield the right-of-way, disregarded the traffic signal, or committed other traffic violation [20]. They have been shown to underestimate the speed of approaching vehicles at intersections [40]. These type of behaviour does not necessarily mean that they deliberately break the laws or engage in unsafe actions. Rather, the literature suggests that factors such as inattention, perceptual lapses, misjudgment, slow reaction time, illiness, poor vision could be implicated [20]. For example, their failure to give way could be attributed to a failure to notice other vehicles as opposed to a willful disregard to road rules. These behaviours have been attributed to various deficiencies in vision, attention, information processing and field independence. Older drivers have difficulty in processing peripheral stimuli to detect targets with high salience for the driving task. Different cognitive theories of ageing could be used to explain the elevated number of older driver related crashes at intersections. Older drivers experience performance decline in situations requiring selective attention, sustained attention, and dual task completion [4]. They also have greater difficulty in processing peripheral stimuli. These tasks require fast, dynamic and flexible attentional shifts which are essential to perform safe intersection manoeuvres. The above limitations together with a slower reaction time may contribute to a higher exposure to crash risks on intersections.

Existing approaches to assisting older drivers focus on simplifying the ergonomics of in-vehicle technology such as navigation system [27], [15]. Although such approaches could improve driver's interactions with navigation systems, we argue that navigation systems do not address older driver exposure to crashes directly. Our crash data analysis show that the elderly drivers exposure to crash increases when performing a particular maneuver on a particular road geometry such as crossroads or T-junctions. The crash risk associated with such situation cannot be remedied directly with navigation systems. The use of navigation systems influences decision making related to route choice, and are therefore situated at Michon's strategic level. Maneuvering on intersections is a combination of both the tactical and operational levels of decision making. A navigation system is unlikely to have impact on these two levels.

A gradual assistive device appear to be the most suitable to intervene at different phase of an intersection manoeuvre. The system could firstly improve the driver's awareness of threatening vehicles with multi-modal warning mechanisms. Such a mechanism should be able to call attention to approaching difficulties, signal risky events and help the driver to focus on the most critical task. If it is not manually impossible to avoid a crash (time to collision less than 2 seconds) then the assistive device should take control of the vehicle to attempt to avoid the crash. A combination of existing Advanced Driving Assistance Systems (ADAS) such as object detection, collision avoidance systems and lane departure systems could be integrated and extended to provide such services.

The availability of wireless communication protocols between vehicles and infrastructure (V2I) or between vehicles (V2V) offer great potential to assist drivers on intersections [36]. A vehicle could notify its presence and location to surrounding vehicles using V2V. Future research may seek to specifically identify the characteristics of those intersections that are a high risk for older road users and consider a combination of road-infrastructure and in-vehicle device interventions.

Due to the frailty of older drivers and their high exposure to crash on intersections, ITS technology that could protect them during crashes and help them to manoeuvre safely in intersections would provide the most significant benefits as illustrated in Figure 1. However other interventions that would assist vehicle control (passive or active technology) could also bring some benefits to a lesser extent. It has been shown that older drivers have difficulties in maintaining path, speed, changing lanes, performing precise control, backing and smooth stop. Existing ADAS technology address such issues, however such ADAS were not designed for older drivers.

The evaluation of in-vehicle devices should also consider user acceptance. Older drivers are most likely to suffer the effects of poorly designed ITS [39]. Oxley [26] studied the user acceptance of in-vehicle Navigation, Rear Collision Warning, Mayday system, Night Vision Enhancement and showed that older drivers exhibit a high degree of willingness to consider the use and purchase of, ITS applications. Olders drivers' opinions towards ITS have been shown to be generally high [35].

An important point to note is that the introduction of any ITS system is often accompanied with an increase of potential distractors. This may have increased relevance for the current discussion given the aforementioned potential difficulty of older drivers to cope with complex systems and attend to multiple traffic cues. A simulator experiment with an on-board display system showing the relationships between the driver's vehicle, other vehicles and roadside objects was shown to be effective in increasing the driving performance of younger drivers, but not older drivers [37]. The system made little impact on the problems of car manoeuvring faced by older drivers, which was attributed to an implied increase in cognitive performance from using the system as well as driving. A second test utilising a heads up display (HUD) which provided additional information on the degree to which the vehicle should be turned at each stage was successful in improving driving performance for both young and older drivers alike, without the subsequent increase in cognitive load for older drivers. It can be suggested from this research that systems which provide specific feedback on a display that does not distract from the driving task would minimise any cognitive load impact of ITS systems for older drivers.

As a final note, the current crash data analysis also suggests that considering the needs of elderly drivers in ITS systems may also have a positive impact in assisting drivers of all ages, as demonstrated by the high involvement of all age groups in more complex road environments [10]. It is therefore suggested that while specific interventions should be developed for older drivers, those targeting intersections would have benefits across a wide age range of road users.

6. CONCLUSION

Several studies have identified ADAS that might be able to assist older drivers [10] [22], [38]. Pauzie [27] has shown that

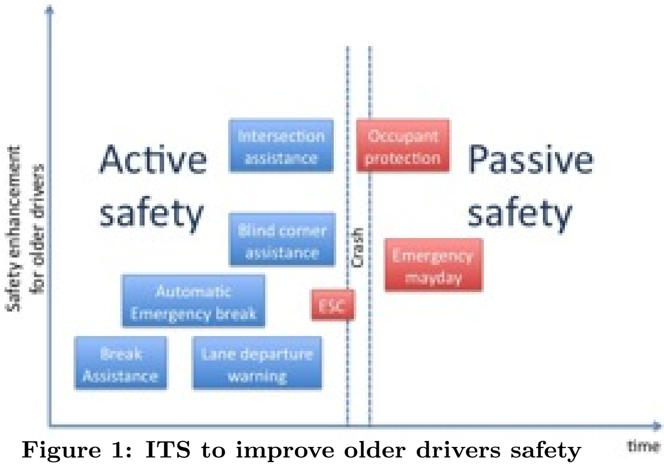

Figure 1: ITS to improve older drivers safety

the ergonomics of in-vehicle technology play an important role in older driver safety safety. A simplified task, simplified dialogue, better legibility and intelligibility of information could improve older driver's performance. This paper focused on the functional requirements of in-vehicle devices to improve the safety of older drivers. We have shown that older drivers are more exposed to crashes in complex driving situations such as intersections. We have argued that Michon's [24] tactical and operational levels are the relevant levels involved in decision making on intersections. Therefore the most promising technology to improve older drivers safety are those affecting tactical and operational levels. The upshot of our findings is that technology based interventions that have impacts on the strategic level, such as navigation systems, are likely to have less safety benefits than those operating at the tactical and operational levels.

There is some encouraging evidence that low-cost safety improvement at intersections such as enhanced traffic signal conspicuity could improve older driver safety [2]. As olders drivers' opinions towards ITS is generally high [35], there are opportunities to enhance their safety with in-vehicle technology. Much research remains to be done to establish the benefits of ADAS for older drivers [6]. The benefits that existing cooperative systems such as V2V or V2I could bring to older drivers have not been fully evaluated. This is despite the fact that V2V and V2I could improve safety on intersections and therefore could be beneficial to the elderly. There is a need to investigate new ways of prompting older drivers to take action, considering their capabilities. For example motor priming and cognitive priming are un-tapped HMI approaches that have not been explicitly experimented in vehicles. ITS is one type of intervention that should be complemented by others including education about self regulation of driving (e.g avoiding intersections, night driving [23]). Continuing research on the extent to which older drivers appropriately use technology and self-regulate their driving is warranted. Much remains unknown about the specific circumstances leading to older driver's crashes and research needs to be conducted in a naturalistic setting as opposed to driving simulators.

7. REFERENCES

[1] I. Ajzen. *From intentions to actions: A theory of planned behaviour*, chapter Action control. From cognition to behaviour, pages 11–40. Springer Verlag, 1985.

[2] J. Bagdate. Low cost intersection improvements reduce crashes for senior driver. Technical report, AAA Michingan, Deaborn, MI, 2004.

[3] P. A. J. Barham, P. R. Oxley, B. Ayala, and J. Alexander. The ergonomic and safety implications of in-car att devices - evidence from field trials with elderly drivers. In *IEE Colloquium on Design of the Driver Interface*, January 1995.

[4] T. S. Braver, D. M. Barch, B. A. Keys, C. S. Carter, J. D. Cohen, J. A. Kaye, J. S. Janowsky, S. F. Taylor, J. A. Yesavage, and M. S. Mumenthaler. Context processing in older adults: Evidence for a theory relating cognitive control to neurobiology in healthy aging. *J. Exp. Psychol. Gen.*, 130(746-763), 2001.

[5] G. Carone and D. Costello. Can europe afford to grow old? International Monetary Fund Finance and Development Magazine, 2006.

[6] R. Davidse. Older drivers and adas - which systems improve road safety. *IATSS Research*, 30(1), 2006.

[7] D. de Waard, F. J. J. M. Steyvers, and K. Brookhuis. How much visual road information is needed to drive safely and comfortably? *Safety Science*, 42:639–655, 2004.

[8] T. Dingus, J. Antin, M. Hulse, and W. Wierwille. Attentional demand requirements of an automobile moving-map navigation system. *Transportation Research*, 23A(4):301–315, 1989.

[9] B. M. Dobbs. Medical conditions and driving - a review of the scientific literature. Technical Report DRNH22-94-G-05297, Washington: U.S. Department of Transportation., 2003.

[10] B. Färber. Can telematics improve mobility of the elderly? *Gerontechnology*, 1:287–290, 2002.

[11] R. Fuller. Towards a general theory of driver behaviour. *Accident Analysis and Prevention*, 37(3):461 – 472, 2005.

[12] P. Green. Variations in task performance between younger and older drivers: Umtri research on telematics. In . *Proceedings of the Association for the Advancement of Automotive Medicine Conference on Aging and Driving*, 2001.

[13] L. Hakamies-Blomqvist. Older drivers' accident risk: conceptual and methodological issues. *Accident Analysis and Prevention*, 30:293–297, 1998.

[14] E. Hildebrand and E. Griffin. The effectiveness of airbags for the elderly. In *Contemporary issues in road user behaviour and traffic safet.*, pages 263–274. D.A. Hennessy and Wiesenthal and D.L. Hauppauge, NY, us: nova science publishers edition, 2005.

[15] S. J. Kim and A. K. Dey. Simulated augmented rality windshield display as a cognitive mapping aid for elder driver navigation. In *CHI 2009*, pages 133–142. ACM, Aprill 4-9 2009.

[16] M. King, A. Nielson, G. Larue, and A. Rakotonirainy. Projecting the future burden of older road user crashes in Queensland. In *Road Safety Research, Policing, Education Conference*, Melbourne, 2007.

[17] M. Peden, R. Scur■eld, D. Sleet, D. Mohan, A. Hyder, E. Jarawan, and C. Mathers. World report on road tra?c injury prevention. Technical report, World Health organization, 2004.

[18] G. Li, E. Braver, and L.H.Chen. Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers. *Accident Analysis and Prevention*, 35, 2003.

[19] R. Martinez. Older drivers and physicians [editorial]. *Journal of the American Medical Association*, 274(1060), 1995.

[20] D. R. Mayhew, H. M. Simpson, and S. A. Ferguson. Collisions involving senior drivers: High-risk conditions and locations. *Traffic Injury Prevention*, 7(2):117–124, 2006.

[21] A. J. McKnight and A. S. McKnight. Multivariate analysis of age-related driver ability and performance deficits. *Accident Analysis and Prevention*, 31:445–454, 1999.

[22] C. Mitchell and S. Suen. Its impact on elderly drivers. In *13th International Road Federation IRF World*, Toronto Canada, 16-20 June 1997.

[23] L. J. Molnar and D. W. Eby. The relationship between self-regulation and driving-related abilities in older drivers: An exploratory study. *Traffic Injury Prevention*, 9(4):314–319, August 2008.

[24] J. A. Michon. A critical view of driver behavior models: What do we know, what should we do? chapter Human Behavior and Traffic Safety, pages 485–520. Plenum Press, 1985.

[25] R. Naatanen and H. Summala. *Road user behaviour and traffic accidents*. Elsevier, New York, 1976.

[26] P. Oxley. Elderly drivers and safety when using it systems. In *IATSS Research*, volume 20, pages 102–110, 1996.

[27] A. Pauzie. In-vehicle communication systems: the safety in-vehicle communication systems: the safety aspect. *Injury Prevention*, 8:26–29, 2002.

[28] A. Pauzie, C. Marin-Lamellet, and R. Trauchessec. Analysis of aging drivers' behaviors navigating with in-vehicle visual display systems. In *Conference Proceedings In Vehicle Navigation and Information Systems*, pages 61–67. Warrendale, PA: Society of Automotive Engineering., 1991.

[29] D. Preusser, A. Williams, S. Ferguson, R. Ulmer, and H. Weinstein. Fatal crash risk for older drivers at intersections. *Accident Analysis and Prevention*, 30:151–159, 1998.

[30] T. A. Ranney. Models of driving behavior: a review of their evolution. *Accid Anal Prev*, 26(6):733–750, 1994 Dec.

[31] J. Rassmussen. Mental models and the control of action in complex environments. In *Mental Models and Human-Computer Interaction 1,*, pages 41–69, New York, 1990. Elsevier Science.

[32] G. Wilde. The theory of risk homeostasis: implications for safety and health. *Risk analysis*, 2(4):2090225, 1982.

[33] J. Wood. Aging, driving and vision. *Clinical and experimental optometry*, 85(4):214–220, July 2002.

[34] M. A. Regan, J. D. Lee, and K. Young. *Driver Distraction: Theory, Effects, and Mitigatio*. CRC Press, 2009.

[35] M. A. Regan, E. Mitsopoulos, N. Haworth, and K. Young. Acceptability of in-vehicle intelligent transport systems to victorian car drivers. RACV report 02/02, Monash University Accident Research Centre, November 2002.

[36] F. D. Salim, S. Loke, S. W, A. Rakotonirainy, B. Srinivasan, and S. Krishnaswamy. Collision pattern modeling and real-time collision detection at road intersections. In *Proceedings of The 10th International IEEE Conference on Intelligent Transportation Systems, , ,*, Seattle, Washington, USA, Sep 30 – Oct 3 2007. IEEE Computer Society Press.

[37] T. Sato, H. Kawashima, and D. Tatsuru. Age differences in behavioral and visual characteristics while driving with narrow road driving assistance system. In *IEEE Intelligent Vehicles Symposium -IEEE Intelligent Transportation Systems Council*, University of Parma, Parma, Italy, 2004.

[38] S. Shaheen and D. Niemeier. Integrating vehicle design and human factors: Minimizing elderly driving constraints. Technical report, ITS UCDAVIS, 2001.

[39] N. Stamatiadis. Its and human factors for the older driver: the u.s experience. *Transportation Quarterly*, 52(3):91–101, 1998.

[40] L. Staplin and R. Lyles. Age differences in motion perception and specific traffic maneuver problems. *Transportation Research Record,*, (1325):23–33, 1991.

[41] Q. Transport. Queensland crash database. https://www.webcrash.transport.qld.gov.au/webcrash2, 2009.

[42] J. Langford, J. Charlton, B. Fildes, J. Oxley, and S. Koppel. Report on vicroadsÕ older driver surve. Technical report, Project 830, 2004.

[43] G. Wilde. The theory of risk homeostasis: implications for safety and health. *Risk analysis*, 2(4):2090225, 1982.

[44] L. Wolfgang. European demographic data sheet 2006. Technical report, International Institute for Applied Systems Analysis and Population Reference Bureau., Vienna and Washington, DC: Vienna Institute of Demography,, 2006.

[45] J. Wood. Aging, driving and vision. *Clinical and experimental optometry*, 85(4):214–220, July 2002.

[46] R. Zacks and L. Hasher. Cognitive gerontology and attentional inhibition: A reply to burke and mcdowd. *Journals of Gerontology Series B-Psychological Sciences and Social Sciences,.*, 52:274–283, 1997.