

## Has the Time Come for an Older Driver Vehicle?

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### Abstract

The populations of many nations and, indeed, the entire world are growing older. As people age, they are more likely to experience medical conditions and take medications that can make operating a personal automobile more difficult. Once driving abilities begin to decline, older adults are often faced with decreased ability to travel to the places that they both want and need to go, due largely to the lack of non-driving options needed for personal mobility. Thus, due to the preference for and pervasiveness of the personal automobile for satisfying mobility needs, there is a global need to keep older adults driving for as long as they can safely do so. In this synthesis of the literature we explored the question: Has the time come for an older driver vehicle? Great gains in safe mobility for older adults could be made by designing automobiles that take into account, and help overcome, some of the deficits in abilities common in older people. This review provides a background and rationale for an older driver vehicle, including discussions of relevant trends, age-related declines in functional abilities, and the adverse consequences of decreased mobility; discusses research and issues related to vehicle design and advanced technology; explores crashworthiness issues and the unique requirements for older adults; and discusses issues related to marketing a vehicle that has been designed for older drivers. Has the time come for an older driver vehicle? We answer this question with a qualified "yes." There is a global opportunity to improve the safety, mobility, and quality of life of older adults by designing vehicles and technologies that help overcome common age-related deficits. The marketing of these vehicles to older consumers, however, will be challenging and will likely require further market research.

**Keywords:** Traffic safety; Aging and mobility; Vehicle design

### Introduction

In recent years, there has been growing research attention on older drivers and how to help them maintain safe mobility as they age. Although addressing this challenge will require a multi-faceted and multi-disciplinary approach, one promising avenue of research focuses on designing automobiles that take into account, and help overcome, some of the declining abilities that older adults commonly experience. An emerging question in this research is: Has the time come for an older driver vehicle? The purpose of this paper is to present findings from a synthesis of the literature addressing that research question. The paper begins by providing a background and rationale for an older driver vehicle, including discussions of relevant trends, age-related declines in functional abilities, and the adverse consequences of decreased mobility. The next section discusses research and issues related to vehicle design and advanced technology with respect to older drivers. Following that are sections exploring crashworthiness issues and the unique requirements for older adults, as well discussing issues related to marketing a vehicle that has been designed for older drivers. The paper concludes with a discussion and recommendations, based on the literature.

### Methods

Synthesis of the literature involved several steps. First, we developed a set of selection criteria, based on our knowledge of the aging and mobility literature, past work on related topics, and discussions with representatives of the automobile industry. These selection criteria were used to gather appropriate articles, reports, and other documents from the time period of 1960-2012. Several document databases were searched, including: MEDLINE, PSYCINFO, TRID, ProQuest, ScienceDirect, Google Scholar, UM-MIRLYN, and the University of Michigan Transportation Research Institute's (UMTRI's) Library. We also searched relevant websites. More than 500 collected articles were reviewed for appropriateness and those deemed appropriate were collected, organized, synthesized, and included in the review.

### Background and Rationale

Building on a long standing trend of population growth, the world's population soared past 7 billion people in 2011, despite global decreases in birth rates [1]. According to the United Nations Population Fund [1], the dramatic increase in global population over the last several decades has been driven largely by decreases in infant mortality (from 133 deaths per 1,000 births in 1950s to 46 deaths per 1,000 births during the years 2005 through 2010) and increasing life expectancy (from 48 years in the 1950s to 68 years in 2010). The world's population is older today than at any other time in history. The proportion of older adults is expected to continue to increase faster than any other segment of the global population. Projections from the United Nations [2] show that the global proportion of people age 60 and older was 8% in 1950, 11% in 2009, and is expected to be 22% in 2050. These proportions are even greater for more developed countries where by 2050 one-third of each country's population is expected to be age 60 or older. Table 1 shows the percentage of population that is age 60 or older for a number of selected countries.

As the global population continues to age, there will be an increased reliance on the automobile to meet mobility needs. In the US and in many other countries, the baby boomers consider driving to be vital to their independence and well-being [3]. In many countries, older adult

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**Received** October 13, 2013; **Accepted** January 27, 2014; **Published** February 03, 2014

**Citation:** Eby DW, Molnar LJ (2014) Has the Time Come for an Older Driver Vehicle? J Ergonomics S3: 002. doi:10.4172/2165-7556.S3-002

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Country	% Country Population Age 60 and Older	World Ranking (Out of 196)
Japan	29.7	1
Sweden	24.7	4
France	22.7	14
Canada	19.5	30
Australia	19.1	33
United States	17.9	43
China	11.9	65
Brazil	9.9	79
India	7.4	105
Qatar	1.9	196

Table 1: Percent of Population Age 60+ and World Ranking by Country [2].

mobility is closely linked to getting around by personal automobile, either as a driver or a passenger. This linkage partly results from the lack of transportation alternatives [4] and partly from the “driving culture” within which baby boomers grew up. Furthermore, during the years in which baby boomers were first becoming licensed to drive (about 1961-1981), changes in family composition, the tendency to move out of urban areas, the increased affordability of automobiles, and the development of extensive roadway systems made the personal automobile the preferred mode for personal travel [5].

Along with the increase in both the number and proportion of older people will be an increase in the number of older people who are holding licenses and driving. Data from the US show that more than 90% of men over age 65 hold a license and more than 80% of women in this age group hold a license [6], with older women showing large increases in licensure over the past decade. In the US, licensure rates for older women are approaching the rate for older men and this trend is expected to continue [7].

An increase in the number of older adults who hold a driver license is also occurring globally. A recent report by Sivak and Schoettle [8] explored changes in the age composition of drivers in 15 countries. The study found that the percentage of older adults who held driver licenses increased in every country studied over the past few decades. In some countries, these increases were quite large. For example, the percentage of adults age 70 and older in Sweden increased from about 28% in 1983 to about 72% in 2008 [8]. These trends will likely continue.

Not only will there be a larger proportion of older drivers holding

licenses in the future, these drivers will likely be taking more trips and driving longer distances. Based on results of the National Household Travel Survey (NHTS) in the US, the average number of daily trips per older adult increased from 2.4 in 1990 to 3.2 in 2009 [9]. Older adults also seem to be traveling longer distances than in the past, although this trend may be changing. When the 2009 NHTS daily-miles-traveled data are compared with 1990 data, daily miles traveled increased from 18.4 miles to 24.0 miles [9]. However, when compared with 2001 numbers, the average daily number of miles traveled has decreased not only for those ages 65 and older, but also for all age groups. It is possible that this recent downward trend is related to the increasing cost of fuel or a saturation effect, whereby increasing income no longer translates into more driving when incomes are high. Increased driving among older people also seems to be a trend in other countries, although there are few published data available [10].

Whether older adults are at an elevated risk of being in a crash, in particular a fatal crash continues to be a topic of debate in the older driver literature [11-15]. The debate is fueled in part by how crash rates are calculated and the selection of age groups. Figure 1 shows driver fatality rates by age group in the US by miles driven, licensed drivers, and population [6,16]. When rates are expressed by population, driver fatality rates are highest for young drivers and slightly elevated for drivers over age 75. Older adults, however, are less likely to hold a license and drive less than those in the middle age groups [12]. In the US, young drivers also are less likely to hold a license and drive less than those in the middle age groups. Thus, when fatality rates are calculated by licensed driver and by miles driven, the rates for both the youngest and oldest drivers are significantly elevated when compared with rates for drivers age 30-65, suggesting higher crash rates for these age groups. Figure 1 also shows that, at least in the US, driver fatality rates do not begin to increase until about age 70 or 75. These increases could be masked if the fatal crash data were combined for all drivers age 65 and older.

Figure 2 shows population-based fatal crash rates by age group for six countries from the *International Transport Forum IRTAD Road Safety 2010 Annual Report* [17]. These countries were selected based upon having comparable rates and being spread around the globe. Crash rates by distance driven or licensed driver were not available for these countries. Note that despite great variability in these curves, the fatal crash rates in most of the countries for drivers age 65 and older

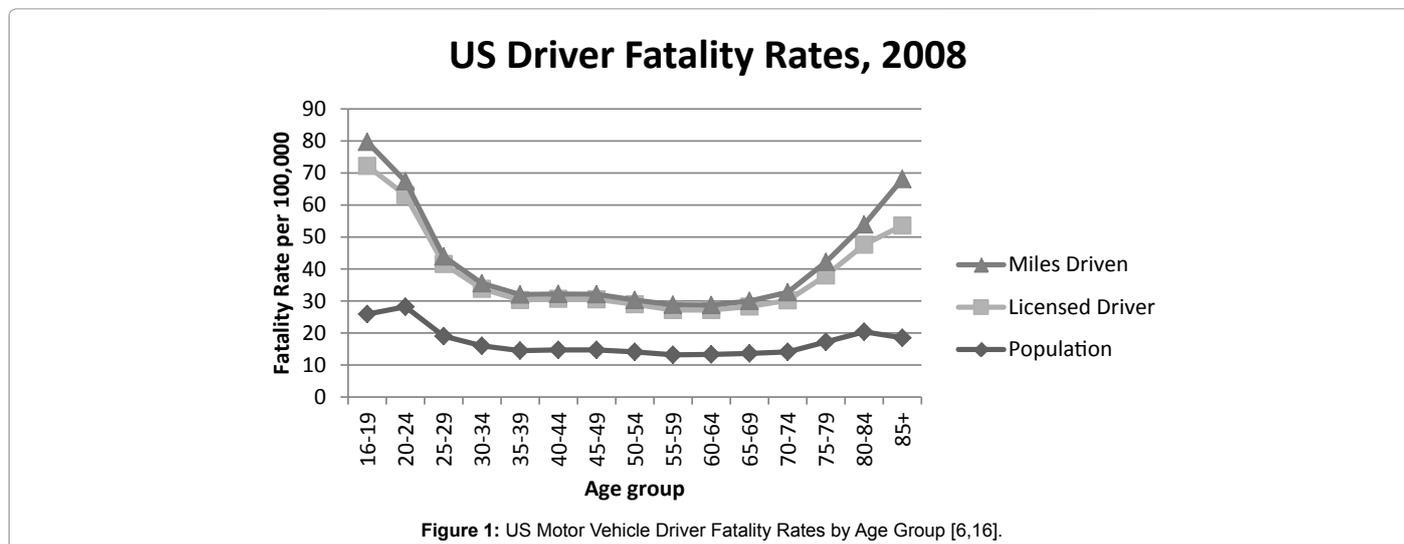


Figure 1: US Motor Vehicle Driver Fatality Rates by Age Group [6,16].

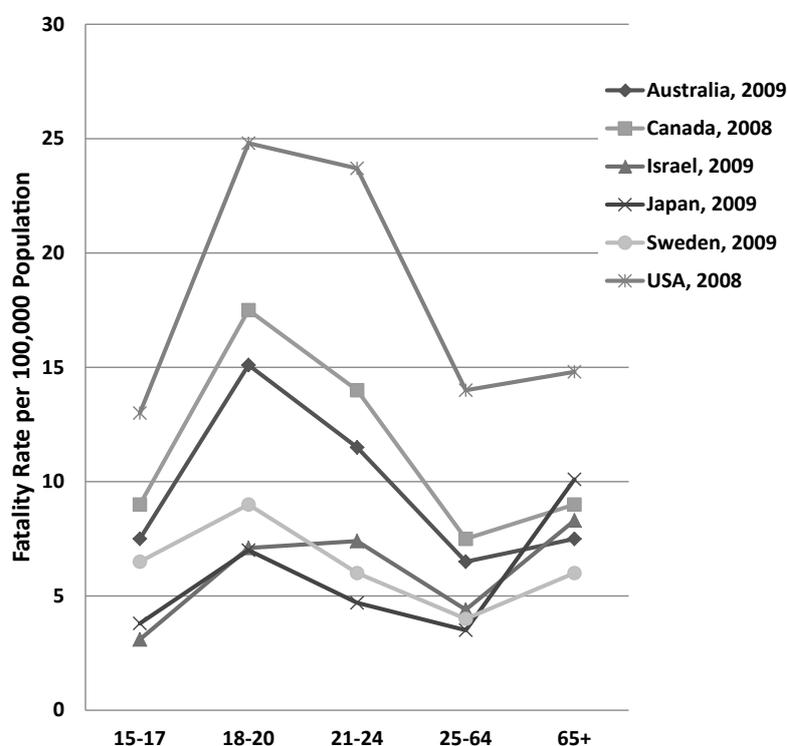


Figure 2: Fatal Crash Rates per 100,000 Population by Age Group in 6 Countries [17].

are higher than for drivers age 25-64, suggesting that older adults have a higher fatal crash risk in many countries across the globe.

### Age-related declines in functional abilities

The complex task of driving involves several types of functional abilities, broadly categorized as psychomotor, visual, and cognitive. Frailty is also associated with growing older. As people age, they may experience declines in these functional abilities as a result of age-related medical conditions, the medications used to treat these conditions, and/or the normal process of aging. Declines in any of these abilities can make safe driving more difficult.

**Psychomotor:** Psychomotor functioning has to do with an individual's ability to coordinate, control, and orient parts of his or her body [18]. Declines in psychomotor functioning can increase the difficulty of vehicle ingress and egress, using vehicle controls, and taking cargo in and out of the trunk [19,20]. Several aspects of psychomotor functioning can degrade with increasing age, including reaction time [e.g., 21,22], flexibility [e.g., 23], coordination [e.g., 24], and strength [25-27].

**Visual:** Driving is an activity that is highly dependent upon visual information. Declines in visual abilities are common with increasing age both through the normal aging process and the increased prevalence of eye diseases [28,29]. Collectively, a number of visual abilities are more likely to decline in older adulthood including: static and dynamic visual acuity [30-34]; sensitivity to light [35,36]; glare recovery [37]; contrast sensitivity [38-40]; and useful field of view [41-43].

**Cognitive:** Good cognitive or thinking abilities are critical for safe driving. Cognitive abilities allow a driver to acquire important information in the driving environment and elsewhere and to make

good operational, strategic, and tactical decisions about driving [12]. Although there is great variability among older adults, several cognitive abilities are more likely to show declines as one ages, including divided attention, selective attention, speed of processing information, spatial cognition, and executive function [44-51].

**Fragility/Frailty:** Both fragility and frailty are commonly associated with old age. Fragility refers to increasing inability to withstand disease or injury. In terms of motor vehicle crashes, fragility is the likelihood of sustaining a greater level of injury for a given amount of force [52]. Thus, for a crash of given dimensions, a person who is more fragile will sustain a great level of injury. According to Kent [53], the biomechanics of fragility involve age-related reductions in bone density, declines in bone area, and changes in bone morphology/geometry that make bones more likely to fail. Frailty, on the other hand, refers to the ability to recover from a disease or injury. Although there is no agreed upon measure for frailty [e.g., 54-57], physical components of frailty may include: weakness; muscle atrophy (sarcopaenia); weight loss; physical inactivity; and slowed movement [55]. Like other age-related conditions, frailty is more common in old age but not all old people are frail [58]. A large-scale study found that the incidence of frailty in Canada was 2% for people younger than age 30, 22% for those age 65 and older, and 44% for those age 85 and older [58]. People who are frail are at a significantly increased risk of death or disability from an injury or disease, when compared with people who are not frail [59]. Taken together, frailty and fragility are considered to be a major reason for the increased risk of death for older adults in traffic crashes [60-62].

### Consequences of driving reduction and cessation

Given the greater likelihood of medical conditions that can compromise safe driving skills and the higher risk of a fatal crash in

older adulthood, it might be thought that getting an older driver to reduce or stop driving should be encouraged. Indeed, in cases where a comprehensive evaluation shows that driving abilities have declined to unsafe levels, and options for overcoming or compensating for these declines are not feasible, drivers should stop driving. However, the older adult population is arguably the most heterogeneous segment of the population and many older drivers are able to continue driving safely. In addition, the lack of available and effective alternatives to driving for meeting ones mobility needs often means that stopping or reducing driving leads to reduced mobility. As shown in a wide variety of studies, stopping or reducing driving is a stressful experience for many older adults, resulting in a poor psychological outlook and reduced quality of life [63]. Loss of driving has been associated with increased social isolation [64,65], reduced independence, mobility, and freedom [66-68], self-reported feelings of low self-worth, low self-esteem, and loss of identity [69], and increased depressive symptoms [70-72].

### The need for a vehicle designed for the older driver

The discussions above identified several factors that have implications for an older driver vehicle. The world's population is aging. Older adults in many countries will likely drive more than previous cohorts. For a variety of reasons, older adults will continue to need and prefer the personal vehicle for meeting mobility needs. Losing access to the personal vehicle, such as losing one's driver license, has many adverse consequences. Based on these factors, there is a clear worldwide opportunity to positively impact global safety and mobility among older adults by designing a vehicle that recognizes and helps to overcome some of the driving abilities that commonly decline in older adulthood. Further, there also seems to be an opportunity to impact not only driving safety but also older adult mobility and driving/riding comfort.

### Vehicle Design and Advanced Technology for Older Drivers

Designing motor vehicles and advanced technologies for an older adult population is not a new idea. Several researchers have suggested that vehicle designs and advanced technology could be adapted to make driving easier, more comfortable, and safer for older adults [19,73-80]. At the same time, many researchers have pointed out that research in this area is lacking [12]. In this section, findings from the literature on adaptive devices, vehicle design features, and advanced technologies that could benefit older adults who are experiencing declines in driving abilities are reviewed.

#### Adaptive devices

Vehicle adaptive devices are aftermarket devices that can assist drivers in making driving tasks easier and safer when they are experiencing declines in driving abilities [81-83]. Adaptive devices are available for: vehicle ingress and egress (e.g., additional bars and handles; swivel seats; key turners); seating (e.g., seat belt extensions/easy reach handles; custom armrests); steering (e.g., spin knobs; special grips); throttle/braking (e.g., pedal extension; hand throttles); and auxiliary controls (e.g., multifaceted mirrors; adapted dashboard controls) [81]. The current best practice for adaptive devices is to work with an occupational therapist who can determine specific declines in driving abilities, suggest appropriate accommodations, and train the driver on proper use [84]. Unfortunately, few of these adaptive devices have been formally evaluated for safety or improved mobility.

#### Vehicle design

Although research on vehicle design for older occupants is

sparse, some studies have addressed design categories that might be relevant for people who are experiencing age-related declines. These categories are: getting in and out of the vehicle (ingress and egress); seating; visibility of the external driving environment; cargo areas; and dashboard controls.

**Ingress/ Egress:** A nationwide survey of more than 1,000 people in the United Kingdom (UK) investigated issues that older drivers had with using motor vehicles [19]. About 80% of the sample was age 65 and older. The study found that when compared with younger respondents, older drivers were significantly more likely to report difficulties both entering and exiting the vehicle, with nearly one-third of older adults reporting difficulty with ingress, and about one-quarter reporting difficulty with egress. Respondents who reported ingress/egress problems were asked which design features contributed to this problem. In order of frequency, respondents reported the following: door sill; seat cushion; steering wheel; cant rail (top of door frame); door; seat back; A-pillar; and the dashboard fascia. The specific issue with the features (e.g., door sill being too low or too high) was not reported.

A focus group study of older adults in Canada also found that older people report difficulties with vehicle ingress and egress [85]. In this study, respondents reported that declines in psychomotor abilities, such as strength and balance, were the main reasons for these difficulties. Respondents reported the following difficulties with vehicle ingress and egress: opening and closing the door; lowering their body into seat or raising their body from the seat; and lack of good interior vehicle lighting at night. The vehicle design features that respondents mentioned as factors contributing to ingress and egress problems were: small door aperture size; low seats; low door frames; raised door sills; heavy door weight; and the location/absence of handles.

**Seating:** Seating comfort and being able to adjust the seat for safe driving are important vehicle design features. The Herriotts [19] study found that about 95% of older drivers reported that they could adjust their seat to a comfortable and safe position. However, significantly more older drivers reported using a "bead mat" (6%) or an extra seat cushion (25%) while driving, compared to drivers younger than age 65. Thus, seat comfort is clearly an issue for some older adults.

**Visibility:** An important vehicle safety feature is the design of windows and mirrors so that a driver has good visibility outside of the vehicle. Studies suggest that older adults have some difficulties using and adjusting vehicle mirrors. A recent study evaluated CarFit, an educational program that teaches older drivers optimal alignment for vehicle features, such as mirrors [86]. The study found that many older drivers reported difficulty seeing outside objects with the left (26%) and right (32%) mirrors. After proper mirror adjustment by the trained CarFit technician, nearly all drivers reported improved visibility.

Older drivers also report that they have difficulties turning their heads to see out the back and side windows. The nationwide study in the UK [19] found that significantly more older drivers (56%) reported difficulties with turning to see out the back window. Of those who reported this problem, 74% reported that the difficulty arose from limited neck mobility and 14% reported that the headrest restricted them.

**Cargo areas:** Although not related to driving safety, the cargo areas of a vehicle, such as the trunk or hatch, are important vehicle features for older adults. The Herriotts [19] study found that about 17% of all drivers reported difficulties putting objects into and taking objects out of the cargo area, with no significant difference by age group. However,

of those who reported such difficulties, significantly more older adults reported that the difficulties resulted from having to lift heavy objects into or out of the cargo area. The Canadian focus group study also found that older adults report problems with heavy objects in cargo areas [85]. Older adults reported that they preferred cargo areas that required minimal bending or stooping for use. The study also found that many older adults reported using the back seat as a cargo area rather than the vehicle trunk, so that objects did not have to be lifted as high.

**Dashboard controls:** Dashboard controls include the gauges, dials, knobs, and buttons used for controlling the vehicle lights, wipers, climate control, radio, and information systems. A recent focus group study in Alabama assessed older drivers' attitudes about dashboard designs in vehicles [87]. Through detailed comment analysis, the study identified dashboard design features that were considered mostly negative by participants. These features were: a lack of uniformity of symbols; difficulty learning how to use the dashboard instruments from the owner's manual; limitations in adjusting dashboard lighting in the daytime; use of lettering that is too small to see; and the complexity of radio/entertainment systems. Features that were considered to be the most positive were the number and format of gauges; the presence of a GPS navigation system; and the coloring of dashboard controls. Focus group work in Canada with older adults has found similar results regarding dashboard controls [85]. This work also found that some older adults reported not wanting to use dashboard controls while driving because of the distraction those interactions caused, with some reporting that they had the passenger make necessary adjustments.

### Advanced technology

New vehicle technologies can increase safety, driving enjoyment, and mobility for older adults [73,77]. These systems vary in the types of information they utilize and provide to drivers as well as the degree to which the technologies assume control of the driving task. Collectively, these systems have been called Intelligent Transportation Systems (ITS). According to Molnar, Eby, St. Louis, and Neumeyer [88], ITS for older drivers should be affordable, easy, and safe to use. Few ITS technologies have been developed by taking into account the common age-related declines found among older drivers. One particular concern is that poorly designed ITS technologies could increase distractions and the driving workload for older users, thereby reducing driving safety. To achieve widespread use of ITS by older drivers, ITS technologies of tomorrow will need to be designed to ensure that safety is enhanced rather than reduced [89,90].

Although the research on older drivers' use of advanced technology is limited and is generally conducted with small sample sizes, a number of studies have documented that older adults often use ITS technologies differently than younger people [73,90-95]. For example, in an evaluation of Global Positioning System (GPS) navigation assistance technology, Kostyniuk, Streff, and Eby [93] found that older drivers used GPS more frequently than younger drivers but reported that it was their passenger who interacted with the navigation system. Studies also report that older drivers take much longer to learn how to use ITS technology [73,93,96].

There are a number of ITS technologies that have the potential to be of benefit to older adults who are experiencing age-related functional declines. While an exhaustive inventory of these systems was not possible for this paper, we have focussed our review on those that are well established. Here we classify these technologies into two categories [97]: advanced driver assistance systems (ADAS) and in-vehicle information systems (IVIS).

**ADAS:** ADAS are technologies involved in the immediate driving task [98]. Some of these technologies provide highly context-dependent information, such as notification of a roadside pedestrian, while others may take over partial control of the vehicle, such as a system that initiates braking to avoid a collision. Several ADAS applications that seem particularly relevant to older driver safety and mobility are discussed below. Note that these research studies have a limited age range for older adults (few are older than 75 years of age), the populations that participated in the studies were generally healthy and drawn from a convenience sample, and the studies do not track the use or safety of these technologies over the long term (more than a few months). Thus, the conclusions we draw from these studies may not generalize to the oldest or less healthy populations of older adults. Nevertheless, these studies do provide important insights into the potential usefulness and safety of these technologies.

**Night vision enhancement:** Night vision enhancement (NVE) systems use infrared cameras to detect objects and the roadway scene and provide the driver with this information on an in-vehicle display [99]. NVE systems can already be found in some luxury vehicles as an option. Safety and usability studies of NVE systems among drivers of all ages have found that: drivers can understand the information; NVE systems can help people see objects while driving that are difficult to see at nighttime; and the systems produce only a small increase in workload [100,101]. Other studies have found that older drivers use NVE systems less than drivers of other ages but report being satisfied with the systems [102-104]. The safety impacts of NVE systems are not conclusive. Self-report data suggest that NVE systems do not increase distraction and reduce the need to look at oncoming headlights that produce glare [100,101].

**Forward collision warning:** Forward collision warning systems use radar information to determine changes in distance to forward objects. When this distance decreases to a level where a collision is likely, the system will warn the driver and/or originate vehicle braking. Studies that have investigated the safety benefits of forward collision warning systems among older adults have found that: acceptance was high as long as the system did not produce too many false alarms; older drivers had greater safety benefits than younger drivers; older drivers drove more slowly than younger drivers and maintained longer headways from forward vehicles; and older drivers viewed the system more favorably [91,105-108].

**Adaptive cruise control:** Adaptive cruise control (ACC) systems not only maintain a driver-set vehicle speed, but also maintain a set distance from forward vehicles without the driver having to use the brake or throttle [109-111]. Safety and usability studies of ACC among drivers of all ages have found that: driver workload and stress were reduced when using ACC; and drivers trusted the system [112,113]. A study of ACC use among both older and younger drivers under natural driving conditions found that all drivers were very pleased with the system and thought it was trustworthy and safe [110]. The authors reported no crashes during the period of ACC use and, based on several analyses, concluded that ACC was safe.

**Lane departure warning:** Lane departure warning (LDW) systems help drivers avoid drifting off the road by warning a driver when the vehicle starts to drift out of its travel lane through the use of side cameras and video analysis [114]. The alert is usually directionally-linked so that a lane departure to the right would produce a warning signal to the right, such as the right side of the driver's seat. Safety and satisfaction studies of LDW systems have found that among young

drivers, the system can help prevent crashes related to drowsy driving [115]. A study in a natural driving environment among young, middle-age, and older drivers found that drivers of all ages tended to stay closer to the center of the lane, use turn signals more, and have fewer lane excursions when compared with driving without the system [114].

**IVIS:** IVIS technologies provide the driver with information and allow communication from and to the driver [97]. Generally this information is not critical for the moment-to-moment control of the vehicle but is useful for making strategic driving decisions, such as deciding where to make a turn. Two IVIS technologies that seem particularly useful for older adults are discussed below.

**Navigation assistance:** Navigation assistance or route guidance systems combine GPS vehicle location information with electronic routing algorithms to provide drivers with turn-by-turn navigation assistance as they drive. These systems are commonly found in vehicles and can be added as an easily fitted aftermarket device. The safety and usability of navigation systems among older adults has been well-researched. Collectively, these studies show that older drivers: use the systems frequently; report some distraction from the systems; are more willing to travel to unfamiliar locations when using the system; report increased feelings of safety, confidence, attentiveness, and relaxation when using the system; have great difficulty reading the navigation assistance displays; take longer than young drivers learning to use the system, particularly entering destinations; and more often report using them with a passenger [91,92,116-119]. Given the low cost of commercially available systems, ease of their installation, the positive regard drivers have for them, and the fact that they seem to be safe, route guidance systems are a very promising advanced technology for helping to maintain safe mobility in an aging society.

**Automatic crash notification:** Automatic crash notification (ACN) systems automatically contact emergency medical services personnel in the event of a crash and transmit vehicle location information and, in some systems, crash severity [120,121]. Clearly, ACN systems are not designed to facilitate mobility, but studies show that these systems can improve safety by getting emergency personnel to the crash scene more quickly [120,122-125]. No research has directly considered the safety benefits of ACN systems for older drivers, but it is reasonable that ACN systems would provide greater safety benefits for older adults.

## Crashworthiness for Older Adults

Crashworthiness refers to the safety performance of a motor vehicle in a crash [78]. In its broadest sense, it encompasses a variety of vehicle features intended to provide crash protection to occupants in the vehicle, including structural designs, seat belt systems, and airbags. Older vehicle occupants present a unique set of challenges for improving crashworthiness [53]. As discussed earlier, while there is great heterogeneity among individual older adults, as a group they are more fragile and frail. In addition, they tend to be involved in different types of crashes and different crash severities than younger drivers. These differences in crash exposure or environment, combined with the greater fragility and frailty of older adults, result in changes in the distribution of crash-related injuries as people age [53]. Consequently, there is a greater need to improve the crashworthiness of vehicles to provide better protection for older drivers in the event of a crash [126].

## Crash/injury patterns of older drivers

**Type of crash:** There is considerable evidence that older drivers, as a group, are over-involved in intersection crashes relative to younger drivers [e.g., 60,127-132]. For example, Langford and Koppel [60]

examined national fatal crash data for Australia for the period 1996-1999 and compared crashes among three driver age groups: middle (40-55), young-old (65-74), and old (75 years and older). They found that the percentage of fatal crashes at intersections was 50% for the old age group compared with only 21% for the middle age group, while the young-old had 35% of fatal crashes at intersections. Similar work in the US using national fatality data has found that when compared with middle age drivers, US drivers age 65-69 were 2.3 times more likely to be in an intersection crash, and drivers age 85 and older were 10.6 times more likely to be in an intersection crash [133].

Older drivers are also more likely than younger drivers to be involved in multiple-vehicle crashes [60,128,134]. Langford and Koppel [60] found that 74% of older driver fatal crashes involved multiple vehicles compared with 60% for middle aged drivers. This outcome is not surprising given the high percentage of intersection crashes among older adults and that older drivers are underrepresented in alcohol- and illicit drug-related crashes [60,134].

**Severity of injury:** Age is one of the most important factors affecting an individual's risk of injury in a motor vehicle crash [135]. As people age, they become more vulnerable to injury because it takes less energy to cause tissue disruption and damage, and older adults' skeletal structures are more easily damaged through bone loss [126,136]. Numerous studies have documented this increased susceptibility to injury among older drivers [e.g., 137-142].

**Patterns of injury:** While it is clear that older drivers are more likely to sustain injuries in a crash, less is known about age-related differences with regard to specific types of injuries [62]. The most consistent study finding is that the risk of chest injury increases with age and that fractures to the chest may be the most significant difference between older and younger vehicle occupants [62,135,142-146]. The most common chest injuries among older adults are to the chest wall and include rib fractures, flail chest, and sternum fractures [146].

## Challenges for Improving Crashworthiness

Considerable gains have been made in improving crashworthiness for vehicle occupants over the past several decades [147]. While these efforts continue, some special challenges have been identified with regard to improving crashworthiness for older adults. First, despite evidence that older drivers have distinct crash patterns relative to those of younger drivers, there is still relatively little information regarding injury patterns for specific crash types involving older adults; therefore, more research is needed on the relative protective influences of vehicle size, design, and safety features for older adults [126]. This is particularly true for emerging crashworthiness technologies.

A related challenge is that for the most part, the design and testing of crashworthiness features, including restraint systems, have not been fully responsive to older adult anthropometry and performance. For example, Charlton et al. [126] argued that until recently, vehicle designs were largely based on young adult anthropometry and performance, which meant that the ergonomic specifications of modern vehicles did not necessarily take account of the needs of older people. They pointed to a growing body of literature describing changes in physical and performance characteristics across the adult age span that needs to be taken into account in the design of vehicles.

A third challenge for improving crashworthiness for older adults, according to Brumbelow and Zuby [148] is that the progress made in improving frontal crashworthiness and the promise of emerging active safety technologies have led to a reduced focus on further passive safety

improvements. They pointed to the continuing need for improvements in crashworthiness, given that no combination of active safety technologies will completely prevent all crashes; thus, crash-related deaths and injuries will continue to occur. Based on examination of data from NASS-CDS, the authors identified a need for future test programs promoting structural designs that absorb energy across a wider range of impacts to potentially reduce serious injuries in frontal crashes. In addition, they concluded that further restraint system improvements might require technologies that adapt to occupant and crash circumstances, but noted that it is unclear what types of full-scale crash testing would encourage these improvements.

A final challenge has to do with trying to meet the often conflicting demands of safety and vehicle usability. One aspect of usability is comfort for vehicle occupants. As discussed by Udama [149], decisions on designs of new vehicles are currently driven by the vehicle interior's dual role as both a comfort cabin and a safety cage. At the same time, the requirements for satisfying each of these roles are often quite different and in conflict with one another. While observing a recent trend of increased emphasis on vehicle safety, Udama [149] pointed to the need for blending together safety and styling to produce a total quality vehicle. Vehicle styling constraints can also have an adverse effect on safety as in the case of hood and trunk geometry that can lead to reduced driver visibility.

## Marketing Vehicles to Older Adults

The baby boomers represent a significant and influential segment of the car buying market. Currently making up the single largest market for luxury automobiles and at the peak of their economic power, the baby boomers signal the new wave of older consumers [74]. Despite this, Coughlin [74] argued that the automobile industry has failed to keep pace with the aging of the baby boomers and their changing approach to purchasing decisions, with regard to both the vehicles produced and the strategies used to market them. This reflects a broader trend of older consumers having been largely ignored in the general market place until fairly recently [150]. The focus on older consumers in the US and elsewhere is now growing, in large part because of the aging of the population in most industrialized countries. In this section, findings from the general marketing literature relative to older consumers are highlighted, as well as findings specific to vehicle marketing.

### Overview of older consumer market

The evolution of marketing efforts directed at older consumers has been characterized as having three distinct stages: 1) total neglect prior to 1980; 2) trial-and-error marketing in the 1980s (often based on stereotypes and anecdotal evidence rather than reliable information); and 3) increasing commitment and caution from the 1990s onward [151]. One important lesson learned from the second stage was that product marketing that stigmatized or labeled people as "old" was ineffective and could actually lead to a backlash by the intended market segment. The sense of caution characterizing the current stage came about in part due to these past marketing errors and in part to the growing recognition that older consumers represent a diverse and complex market.

Although older adults represent arguably the most heterogeneous segment of the population, there are some general patterns among older consumers as a group that have been identified in the literature. One of the most consistent findings is that for most older consumers, self-perceived age is younger than actual chronological age [152-154]. For example, findings from interviews of senior executives in the retail

property industry and focus groups with shoppers in the UK suggested that older consumers do not see themselves as old as they are and are often drawn to products aimed at younger consumers [153]. Sudbury and Simcock [154] identified several distinct segments of older consumers, based on their age and various individual characteristics. However, the common theme among each of the groups was that individuals felt about 10 years younger than their actual age.

Moschis [151] has summarized general findings from the literature with regard to older consumers. In comparison with younger consumers, older consumers have been found to: save/invest more; spend more on luxury products and services; shop during morning hours; prefer "one-stop" shopping; consider shopping to be a social event; be very convenience-oriented; patronize reputable/traditional outlets; seek personal attention and special services such as valet services; choose products based on quality and name brand; be less price conscious and deal prone; use credit as often; be as likely to show non-significant responses to sweepstakes and telemarketing; and complain less when they are not satisfied with something they have bought. Based on these research findings he recommended several marketing strategies. Strategies with particular relevance to the topic of this paper included: segmenting the older consumer market based on life events and circumstances (which influence individual needs and lifestyles), rather than based on age; developing products with an intergenerational or universal appeal (i.e., products that can satisfy the needs of both younger and older consumers but are most beneficial to the older adult); and promoting products in a way that reinforces the "youthful" self-concept many older adults hold rather than emphasizing their old-age status. This last recommendation, in particular, is supported by the earlier finding that older adults tend to perceive themselves as younger than they actually are.

In trying to understand older consumer behavior, it is important to disentangle age-related and cohort-related differences. A cohort or generation can be characterized as a group of people who travel through life together, experiencing similar events at a similar age, sharing a common social, political, historical, and economic environment [155]. There have been numerous efforts to discern common patterns among the baby boom cohort. For example, Reisenwitz and Iyer [156] in a survey of baby boomers found that, with the exception of self-perceived age, there were no significant differences between younger (age 40-49) and older (age 50-58) baby boomers across a large set of behavioral variables (e.g., entertainment-related activities, volunteer-related activities, culturally-related activities, fashion interest, self-confidence, social involvement, work orientation, innovativeness, loyalty proneness, risk aversion, and nostalgia proneness). The authors cautioned against the widely accepted marketing practice of age segmentation in which the baby boomers are split into young and older boomers. However, one limitation of these findings is that none of the baby boomers in the survey sample had actually reached an age generally considered to be old.

The aging of the baby boomers has led to increased attention to how they differ from previous generations of older adults. Coughlin [157] argued that perhaps the most striking difference between the baby boomer generation and previous generations is their expectations; that is, the baby boomers throughout their lives have experienced seamless and affordable mobility, new technology, high style, and the constant promise of improvement. Further, they expect to continue an active and mobile lifestyle as they age. The baby boomers have also been characterized as being more educated, more demanding, and having experienced more technology throughout their lives than any previous generation [158]. Coughlin [158] argued that the aging baby

boomers in developed countries will have mounting expectations for how technological advances can improve their lives that will challenge technology developers and product designers.

At the same time that baby boomers' expectations for technology are increasing, they may face challenges in learning to use new technology systems in their vehicles. There is evidence that older adults use new systems differently than younger adults and may require more training [12]. Shaw et al. [85] found that older adults had concerns about how to use some vehicle technologies and misunderstood how they worked to improve safety. Coughlin [159] has suggested that manufacturers may have to come up with new ways of training drivers of all ages to best use new in-vehicle systems.

Because aging is often accompanied by functional declines in vision, cognition, and psychomotor skills, older consumers have often been considered part of the same market as disabled consumers, with regard to product development, sales, and distribution. However, concerns have been expressed about this approach, given that similarities in physical requirements between older and disabled consumers do not necessarily translate into shared self-perceptions and aspirations [e.g., 158]. Coughlin [74] specifically addressed the issue of the extent to which the vehicle design and marketing process should be planned to appeal to older adults, while at the same time meeting the needs of people with disabilities. Noting that the automobile industry has achieved significant success in introducing design innovations to meet the needs of older drivers, he cautions against focusing only on "needs" as the baby boomers age. He argued that older adults may have similarities in functional requirements but do not see themselves as disabled or equate their age-related functional declines as disabilities. Thus, it will be increasingly important to go beyond an understanding of older adults' functional needs as drivers to understand how their current and future lifestyles can be best accommodated.

Baby boomers not only constitute the emerging wave of older adults, they also represent the largest generation of women drivers and consumers [159]. This poses challenges as well as opportunities for the automobile industry. In terms of marketing, it will be increasingly important to understand and respond to women's preferences and needs in vehicle design in terms of comfort, convenience, and other ergonomic elements.

### Vehicle marketing to older consumers

The aging of the baby boomers and the increasing share of the consumer market they command have led to increased efforts by vehicle manufacturers to market to older consumers. As a first step in this process, many manufacturers have tried to develop a better understanding of changes that older adults experience as they age and what the implications of these changes are for vehicle design and marketing. To this end, Pak and Kambil [160] emphasized the need for manufacturers to understand the various biological, physical, economic, and social changes associated with aging so as to effectively realign their offerings and adapt their communications strategies to the older adult market. They cited the example of the "Third Age Suit" as an approach to sensitize engineers and designers to the physical limitations associated with aging. The suit adds bulk and restricts movement in the knees, elbows, stomach, back, and other key areas of the body. Engineers can wear the suit to experience what limitations in mobility, strength, and visions of someone 30 years older might be like.

At the same time, the general pattern among manufacturers has been to focus on safe and comfortable vehicles that may be specifically packaged and marketed to the general population rather than one

segment such as older adults [161,162]. Such an approach, often termed *universal design*, has been used by human factors engineers to design vehicles for people who are older as well as for the general population (e.g., vehicles that include larger knobs and instrument panels). The idea behind universal design is that it can improve vehicle use for older adults while at the same time benefiting other age groups [163]. This approach is considered especially promising, given the widespread view that baby boomers will not buy vehicles marketed specifically as user-friendly for older adults [162]. Some of the distinct vehicle features that have resulted from a universal design approach include raised seating for easier ingress and egress, extra-wide doors, large controls, non-reflective interior surfaces to reduce glare, power-swivel driver and passenger seats, and all-wheel drive [162].

### Discussion and Recommendations

Has the time come for an older driver vehicle? We answer this question with a qualified "yes." Based on the information reviewed here, there is a clear global opportunity to improve the safety, mobility, and quality of life of older adults by designing vehicles and vehicle technologies that help overcome common age-related deficits. As technologies and designs are developed, they will need to be tested for safety with a wide range of older adults, including those who are experiencing declines in driving abilities. These studies should also investigate driving safety over a relatively long period of time in real driving conditions. Given the global aging and driving trends, it is reasonable to assume that there will be a large market of older consumers who may be interested in purchasing vehicles that help them to continue driving for as long as they can safely do so. The marketing of these vehicles to older consumers, however, will be challenging and will likely require further market research.

The development of vehicle design features, new automotive technologies, and crashworthiness systems in the future should be guided by both knowledge of frailty/fragility and its effect on crash outcomes, as well as knowledge of common driving-related declines in psychomotor, visual, and cognitive abilities. Utilizing principles of universal design is recommended. In most cases, vehicle design changes and technology developments that make driving safer and easier for older adults will also help drivers of any age. However, because of age-related frailty and fragility, universal design principles may not always be ideal for improving crashworthiness.

At the same time, developers need to recognize that older adults are a highly heterogeneous group. Design strategies that allow for some degree of customization may be particularly beneficial. Offering certain design features and/or technologies as an optional package may be one method to allow a small level of customization for older adults. How such an optional package is marketed will require careful thought, but it is clear that it should not be marketed as being specifically for older adults or people with disabilities. Another way to allow a degree of customization is to have programmable features that adjust themselves based on the driver characteristics - similar to some current vehicles that can sense who the driver is based on a key fob and then adjust seats, mirrors, and other features to fit that driver's preferences. Although not possible at present, another method for customizing vehicle features and technologies is to have a vehicle capable of sensing the driver's characteristics in real time (including psychomotor, visual, and cognitive abilities) and adjust features and interfaces to optimize usefulness given the driver's current status. As an extension to this idea, some researchers have proposed that there could be great traffic safety benefits of continuous in-vehicle medical monitoring of certain physiological data, such as blood glucose level, and the system could

alert drivers when physiological data indicate a contraindication to safe driving, such as hypoglycemia [see e.g., 164].

Independent of the specific design features and technologies for future older drivers, it is clear that training and education efforts will need to be improved. Without adequate knowledge about vehicle features and technologies, the benefits of these new designs may not be achieved and, in the worst case, may compromise safety. Older adults report difficulties learning about current technologies and vehicle features and lack knowledge about how crash protection systems operate. It is highly likely that this situation will continue into the future unless new ways to train and educate older adults are devised. Whether or not this training can take place at a vehicle dealership is unknown and should be explored in future research. Another method for training could involve a third party who provides the training on behalf of either the manufacturer or the consumer. It may also be possible to work with groups like those who organize CarFit events, where trained volunteers provide expert feedback about adjusting vehicles to better fit with an individual driver's characteristics.

Finally, even though we conclude based on synthesis of the literature, that the time is ripe for an older driver vehicle, we qualify that statement by cautioning that the marketing of such a vehicle will be complicated and will likely need to be based on more research. In particular, more research is needed on how older adults process marketing information. Studies are clear that older adults do not resonate to products that are linked to "old age" or being "disabled." On the other hand, if vehicle designs, automotive technologies, and crashworthiness systems are optimized for overcoming many common age-related declines making the operation of a vehicle safer and easier, there is an excellent opportunity to capitalize on these benefits in a marketing strategy for selling cars to older consumers.

### Acknowledgements

The research on which this paper is based was supported by Sustainable Worldwide Transportation at the University of Michigan Transportation Research Institute (UMTRI). The authors thank Dr. Michael Sivak, Ms. Renée St. Louis, Dr. Jonathan Rupp, and Mr. Robert Sweet from UMTRI for their comments on the original research report. We also thank Mr. Jan Aase and Mr. Carl Wellborn from General Motors Corporation, Mr. John Combest from Nissan Technical Center North America, Mr. Jim Keller from Honda, Mr. Yves Page from Renault Technocentre, Dr. Steve Rouhana from Ford, and Mr. Robert Strassburger and Mr. Scott Schmidt from the Automotive Alliance for sharing their insights and helping us focus on the essential issues. Development of this journal article was supported by the Center for Advancing Transportation Leadership and Safety (ATLAS Center), a University Transportation Center and Collaboration between the University of Michigan Transportation Research Institute (UMTRI) and the Texas A&M Transportation Institute (TTI) sponsored by the US Department of Transportation, Research and Innovative Technology Administration (RITA).

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This article was originally published in a special issue, [Driver Safety](#) handled by Editor(s). Prof. Jibo He, Wichita State University, USA