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# How to use cognitive tools to increase sustainability of elderly people mobility?

Hang Cao
*Dept. of Vehicle Technology*
*Budapest University of Technology and Economics*
Budapest, Hungary
hang.cao@edu.bme.hu

**Abstract**
Aging is a major international trend. The effective and long-term development of activities for the elderly is an important issue. Vehicles must improve the range of activities of older people and increase their life trajectory beyond their age limits. With human participation, autonomous vehicles need to improve driving capabilities to drive safely in traffic scenarios and implement sustainable solutions. We will explore the mobility of aging people when riding in traffic and as pedestrians, with the hope of having sustainable development in terms of convenience and safety for aging people in transportation. The discussion is illustrated in terms of the impact on driving behavior, the functionality of vehicle sensors, and the interaction with traffic road users. This paper helps to illustrate that autonomous driving tasks can benefit aging drivers in terms of driver users, vehicle sensors and systems, and road users when dealing with new or unexpected traffic situations. Identifying cognitive changes and relationships is important better to understand the road environment's cognitive processes and behaviors.

**Keywords**
Autonomous vehicle, elderly people, cognitive, mobility

## 1. Introduction

Age problem also has been a worldwide trending issue in the past 30 years, reflects communities' mental health and physical health, and as a popular topic to discuss on mobility. The mobility scheme is exchanging their mobility allowance. Some research results showed that the attention-related risk for elderly drivers increases in complex driving situations. Beyond a certain age, keeping appropriate car driving decisions is hard. Today, congestion is a primary problem in traffic environments worldwide; several accidents occur because of driver inattention and distraction, negatively affecting vehicle fuel consumption (Zoldy and Zsombók, 2018). Some approaches to traffic congestion problems have been proposed, such as analyzing and improving road traffic engineering (Lekić et al., 2019) and managing the road system through Intelligent Transport System (ITS) (Zear et al., 2016). Many researchers address the problem of traffic congestion by using a routing technique (Cao and Zöldy, 2020; Cao and Zöldy, 2021) since vehicles can adopt a new route to avoid congestion. However, traffic congestion at a different location may occur if a high number of vehicles adopt the optimal route. This situation can be considered a scientific, social dilemma in game theory and social psychology (Dawes and Messick, 1980). It is important to realize that the individual rational choice does not coincide with the rational choice for a society (Hiraishi and Mizoguchi 2017）.

The French researchers designed a questionnaire to evaluate aged-driving behavior with comparison. However, findings found that cognitive abilities test via self-evaluation is more effective than driving behavior questionnaire. The self-evaluation measurement includes process velocity and attention. Bergen et al. (2017) classified self-regulation aged drivers into three groups: high self-regulation group, medium self-regulation group, and low self-regulation group, and found that to reduce transportation risk, training avoidance of orientate driving situations and driving weekly frequency is necessary.

Vehicles and their embedded technologies provide people with significant changes in easy and comfortable living. People of different ages need to benefit from such assistance without generating new attention-related risks (JC Marquié, 2010). The US Department of Transportation (USDOT) established five levels of vehicle automation (Alyamani et al., 2017)

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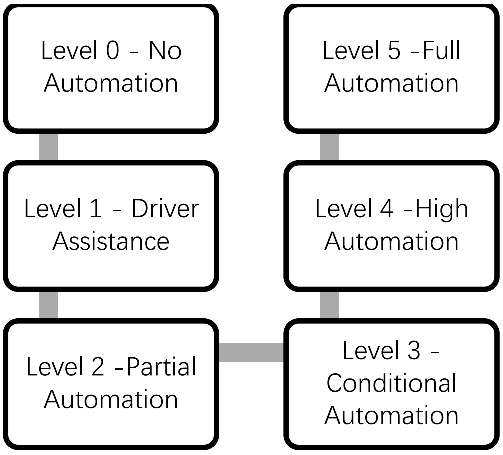


Figure 1. The structure of five levels of vehicle automation (based on Alyamani et al., 2017)

The competency to drive effectively and sustainably involves several cognitive abilities. Anderson and his colleagues (2017) use a neuropsychological composite score to evaluate cognitive and overall driving ability. They proposed a cognitive test including four aspects, i.e., attention, memory, visuospatial and visuomotor skills (Kim and Bishu, 2004). The work explores driving responses and improving unsafe driving sustainability, considering older drivers' risk (Anderson et al., 2005). Sustainability-minded driving refers to vehicle drivers who are environmentally concerned. Rapoport's team categorized the sustainability of driving capability in cognitive performance, driver perceptions, and self-monitoring driving restrictions (Kim and Bishu, 2004; Rapoport, 2013). Changes in cognition lead to actual driving results over time, resulting in typical driving situations and hazardous driving conditions, i.e., crashes and violations (Anstey, 2005; Rapoport, 2013). Cognitive ability, executive function, and memory values can lead to poorer driving performance and increase the risk of collisions (Anderson et al., 2005). Motoyuki summarized the effects of cognitive and physical changes on satisfaction using alternative modes of transportation from the perspective of older adults' mobility (Motoyuki et al., 2006). The speed and quality of specific movements can be measured by considering cognitive factors to improve sustainability (O'Connor, 2020)

Human driver familiarity with the environment and situation will result in different driving styles and performances. Drivers specify helpful information and identify whether the road is driveable from the surrounding environment. Due to adequate awareness of the energy distribution of the obstacle, such as light reflected by surfaces and objects (Sánchez and Araújo, 2021), drivers take action. The scenario for the self-driving car to travel mainly consists of structured and unstructured roads (Chen et al., 2019). Clear boundaries and traffic signs are defined as the features of structured scenario roads. Meanwhile, unstructured roads can be seen as rural areas with no clear boundaries (Chen et al., 2019). Getting self-driving cars to follow established lanes and traffic signs reasonably and legally on structured roads, or to drive safely and smoothly on unstructured roads, is another challenge for self-driving cars (Zöldy et al., 2021).

This paper discusses elderly drivers facing problems and the autonomous vehicle . The rest of the article is structured as follows. Section 2 introduces the elderly driver's cognitive aspects related to the detection of and adaptation to the environment. Section 3 illustrates the autonomous vehicle system cognitive changes considering older people's characteristics. Section 4 presents the difficulty of cognitive changes of autonomous vehicles. Section 5 is the conclusion and discusses expectations concerning the cognitive problem of self-driving cars for elderly people.

## 2. Driver's cognitive ability to adapt to the environment

Mobility is critical to the quality of life of older adults, and all trends suggest that in the next century, most of their transportation needs will be met by private cars. (Schaie and Pietrucha, 2000). **Cognitive flexibility** is the ability to appropriately and efficiently adjust one's behavior according to a changing environment. Some researchers summarized comparisons of what drivers currently do and what they intend to do as behavior surveys in several categories. Li et al. (2021) studied standard driving modes into six categories, i.e., deceleration, stable, acceleration, left turn, right turn, and roundabout scenario case (Li et al., 2020), and collected driving modes with acceleration and angular speed. A roundabout has specific traffic rules to obey. Alyamani concluded that left/mixed-handed drivers show better driving performance when entering roundabouts and approaching intersections (Alyamani et al., 2017). The differences in driving flexibility influence the

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driving errors when exiting roundabouts. Driving errors include driving in the wrong lane, failing to use the indicator light, or using an incorrect directional indicator. Left/mixed-handed people show superior cognitive flexibility in tasks that require such ability as right-handed people.

Hiraishi and his team expand the Time-constrained heuristics search (TCS) process from two cognitive psychological views: prospective theory and present-oriented bias (Hiraishi and Mizoguchi, 2017). Considering that the driver prefers immediate profit and sufficient spare time to ensure a comfortable and relaxed environment, in this case, the driver reaches the goal of finding the optimal route. Strayer et al. (2019) found that 65% of the vehicles supported texting and 25% supported destination entry using a navigation system when the vehicle was in motion.

**Cognitive map**

The study found that older adults have less accurate verbal memory for urban landmarks and less accurate memory for the location of landmarks than younger adults. In addition, the discriminant analysis revealed that older adults relied more than younger adults on certain architectural attributes upon to remember urban landmarks. For example, the naturalness of the surroundings, direct access to the street and unique architectural style, high public use, and high symbolic significance. However, older adults have become much less inexpensive with age and other cognitive impairments for this memory method for their transportation. The car's mapping system will significantly help the elderly to get around. **Cognitive map** is the description of future scenarios and potential situations. Zhang and his colleagues created Fuzzy Cognitive Maps (FCM) to illustrate high-level scenario planning, providing an accessibility method that could give an integrated description of the mental models (Zhang and Jetter, 2018).

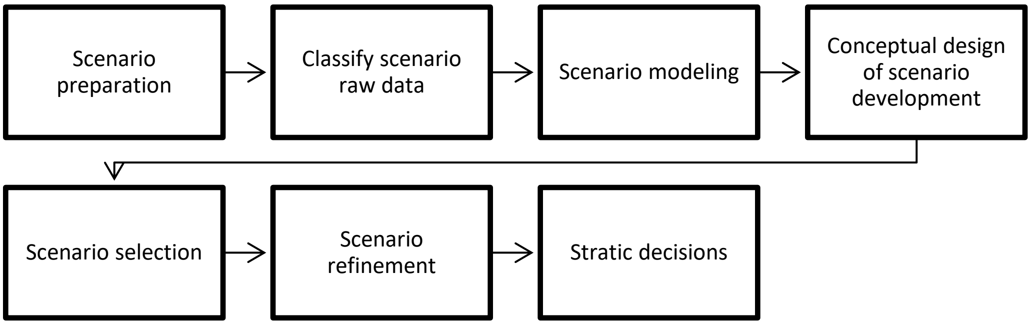


Figure 2. Cognitive scenario planning framework (Felix et al, 2019)

As Figure 2 shows, in the main cognitive maps framework, the key idea is to build and transform the useful scenario data, classifying the scenario raw data and identifying model components, integrating and constructing the cognitive maps scenario, inference complex causal modeling and probabilistic scenario cases. Cognitive mapping will give the elderly a clearer picture of their current and future travel status and routes than possible. For cognitively impaired older people, vehicle systems with cognitive mapping will greatly compensate for the cognitive deficits of the elderly during driving.

**3. Cognitive design on the self-driving car system view**

Most autonomous vehicle (AV) system designs are based on a social-cognitivist assumption to explain navigation tasks and cooperative tasks. The ego car must understand the mission of all navigational tasks and collaborate with other road users, which greatly helps aging people. AVs are equipped with advanced sensors to obtain environmental information, including cameras, lidar, radar systems, etc. The vehicle's software recognizes the objects and the sensors detect road users, which are also responsible for the car's compliance with traffic rules (Sánchez-García and Araújo, 2021). The embedded detection system software cooperates with a digital map to identify the driving situation and make rational driving decisions ( Sánchez-García and Araújo, 2021). Understanding the environment and the decisions are stored in the computational memory. The vehicle expects the same navigation style from other road users, i.e., to share the road information with the other drivers or road users in the same situation, to reach the specific goals of each driver, and to follow traffic rules to take part the interaction.

Cognitive changes include visual scanning, attention, processing speed, executive function, and memory (Donoghue et al., 2012). Visual/manual touchscreen interactions may divert the driver's eyes, while auditory/sound interactions may keep

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the eyes on the road; however, any benefits of the former may not be realized if the auditory or sound interactions take longer to execute than the visual/manual interactions. In many cases, a task can be performed using auditory commands, visual/manual interactions, or a hybrid combination of /audio and visual/manual interactions (Strayer et al., 2019).

The in-vehicle system can help aging people while driving. The audio entertainment in the car system allows the elderly to change the music to different radio stations and satellite radio sources, and also allows them to call and dial their cell phones via Bluetooth connection. The in-car system also helps the elderly to navigate, step by step, in a way that makes it easier for them to get around according to their own characteristics. A cognitive module is introduced in the system architecture to enable the transition from perception to decision-making. The hardware and software systems collaborate to select the best driving strategy through traditional context-aware scenario analysis or AI techniques.

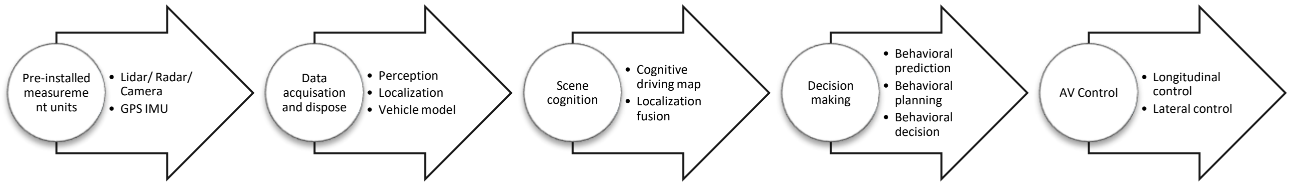


Figure 3. Relationship among AVs sensors, data disposal, and driving behavior planning (Zhang, X et al., 2020; Knoefel et al., 2019)

Figure 3 shows the relationship between vehicle sensors and the manipulation of vehicles. The vehicle body has its own sensory system, i.e., pre-installed measurement units, for example, odometer, inertial measurement unit (IMU), gyroscope, and controller area network (CAN) bus (Knoefel et al., 2019). These self-sensing features instantly detect wheel velocity, yaw angle and steering behavior. GPS and IMU as external sensors determine vehicle destination and real-time position. Environment sensors are used to obtain the surrounding information and other road users' states.

Mobility impairment in older adults appears to predict more generalized disability and susceptibility to other geriatric syndromes (Sims et al.,1999). Some research groups found that falls and vehicle crashes are related in some older drivers. Vulnerable older adults consistently exhibit multiple impairments due to the effects of medications, chronic illness, emotional disorders, and visual and cognitive dysfunction (Sims et al.,1999). These changes include the following relevant declines in ability: decreased mobility, decreased strength, more rapid onset of fatigue, visual deterioration, reduced ability to process information, slowed reaction time, and hearing loss (Smith et al., 1993; Herriotts, 2005). SHIRAI and TAKAHASHI (2018) considered the possible conditions for older people. They designed a skin potential reflex device (SPR) to reach the demand of releasing the elderly stress on mobility, e.g., the weak legs problem for older people. The researchers focused on links between cognitive function levels and crashed risk among older drivers without dementia over a 14-year study period. They also assessed the link between changes in cognitive function over time and later risks of crashes.

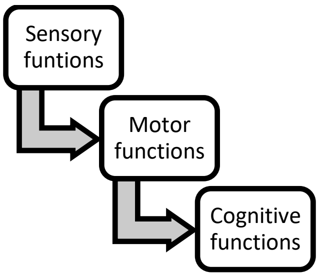


Figure 4. Age-related functional changes for autonomous vehicle

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As Figure 4 shows, age-related functional changes mainly include the interaction of sensory, motor, and cognitive functions. Normal aging and structural changes in the eye lead to a decrease in visual acuity and contrast sensitivity, and this part of the visual limitation becomes more pronounced with increasing age. The cognitive vehicle system of the elderly happens to need to account for such losses. The motor function described with age increases, and the loss of body muscle strength diminishes. Cognitive functions mainly control attention supporting, e.g., visual search, visuospatial skills, and attention switch, suppress irrelevant information and inappropriate responses, multitask, and monitor one's own performance. This pattern will help high correlation on accurate position and maneuver for ego vehicles.

BMW raised the concept of "Environment–Driver–Vehicle" cycle (Hoch, S., 2016) to illustrate the cognitive effect on the vehicle software framework. However, the routes provided by the GPS are not optimal and lack on-demand user requirements. Smith et al. (1993) explores the cognitive field within the in-vehicle framework. The GPS provides the route and coordinates with a satellite communication system to store the available route. The route data are learned, stored, and read inside the cognitive memory for an optimal route provision. The vehicle learns about the routes and matures with route experience by itself over time. Fuzzy modeling was used to examine the effect of cognitive variables on static and conventional parameters (Baranyi et al., 1996). On the body of the car, there are high-resolution cameras that can scan meters in any direction; there are also front and rear radars to detect the environment and nearby objects.

Complex lighting and weather conditions all have different effects on vehicle movement. Various lighting conditions and corresponding scene changes, such as darkness and roads that do not reflect light well, cause significant interference with the images obtained by the camera. Poor weather conditions interfere with the reception of LiDAR point cloud data, resulting in LiDAR's inability to detect obstacles accurately.

**4. Cognitive interaction among road users**

AVs driving route is based on their understanding of the environment and road conditions. For automotive vehicle systems, help older drivers understand the scenario and driving conditions is important. Some road conditions are complex, lead drivers need to give right of way, and turning, those in difficult or unexpected situations involve other road users. Roundabout is one of these complex crossroads. Figure 5 illustrates the ego car route planning category based on the roundabout types, i.e., the traffic sign exits or a no-signal roundabout.

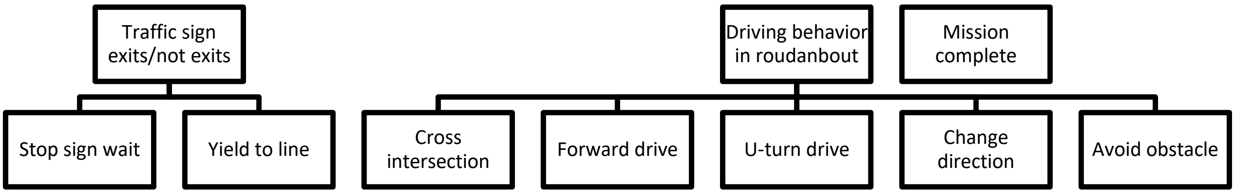


Figure 5. The case of ego car route planning in roundabouts – summary

The ideal case is when the ego vehicle drives without other road users. However, in the real world, traffic needs the vehicle to cooperate. The road users can be passenger cars, large vehicles, pedestrians, and cyclists. Determining the ego car's mission, evaluating other road users' behavior, and quickly and accurately reacting are the critical core of AV interaction. The challenges of transportation "negotiation" are widely discussed in transportation research and cognitive science. Trust in AVs was defined as the tendency to be influenced by the actions of AVs (Jayaraman et al., 2021).

Trust, preference for AV, anxiety, and mental workload are four autonomous vehicle interaction outcomes (Du et al., 2019). Jayaraman et al. find that the autonomous vehicle's aggressive driving depends on the type of crosswalks (Jayaraman et al., 2018) and the presence of traffic lights. Pedestrians' gaze at certain areas/objects, pedestrians' distance to collision, and jaywalking time substantially impact the AV trust (Jayaraman et al., 2018). The pedestrian's trust is fed back to the vehicle's movement, and the two interact to determine the vehicle's travel speed and route.

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Uncertainty reduction theory (URT) is embedded deeply in many research fields and can be applied to cognitive changes between an AV and a pedestrian. The greater the uncertainty, the more people seek information to reduce uncertainty; the more information is provided, the less uncertainty is. Helping avoid sudden automation incidents and adverse emotional reactions play essential roles in autonomous vehicle interaction. AV explanation promotes automation trust since it provides humans with clarity (Du et al., 2019). The effects of explanations, their timing, and the degree of autonomy on drivers' trust, preference, anxiety and mental workload have been tested in 6-8 minute drives ((Du et al., 2019). Driving control moves from the knowledge or rule-based levels towards the skill-based level, reducing the mental or cognitive workload required for the operations involved in the driving task.

## 5. Cognitive difficulties

Driving behavior varies because of the reactions from different driving experiences. Chater et al. (2017) categorized driving ecology and scale of cognitive science challenges with automated negotiating skills. Fatiha and Abdelghani (2017) summarize metacognitive difficulties in the driving context and illustrate methodology based on the combination of quantitative methods, e.g. statistical analysis and qualitative methods related to the drivers' expectations and driving experiences. One's cognition of one's limitations and strengths enables one to choose strategies to accomplish a task in the best possible manner and assess the gap between the performance and goals to manage the risks associated with task complexity properly.

For metacognitive skills for elder people planning, difficulties are in route planning and remembering the itinerary. A metacognitive difficulty in control and monitoring is the lack of sensitivity to inconsistent information about the road environment. Urban environment complexity and drivers' cognitive resources are also problematic: a driver in an urban environment faces an overflow of information from other users, neighborhoods, infrastructures design, roads signs etc. It is also difficult to deal with the information quickly and in real-time (Zöldy M et al., 2021). Furthermore, the cognitive burden of older people belongs to data privacy. How to deal with data using and maintaining data privacy is an important issue.

## 6. Conclusion

Driving automation may become the assistive device of the future. However, partial vehicle automation continues to evolve in the coming decades and needs to consider the needs of people of different ages. Full vehicle automation is still many years away and may completely change the requirements for driving ability. Helping drivers promote sustainability-focused driving patterns and lead the autonomous vehicle to increase cognition aid is essential for the future. Training vehicles to increase cognitive ability from driver to system view will increase the efficiency of traffic users and enable increasingly optimal mobility decisions. For older people, restricting driving is not a good solution for older people's mobility. Moreover, the industry should consider older people's characteristics, cognition state, and social interactions for automotive system design. Let us make the "shrinking world" of elderly people have a more expansive lifestyle.

In addition to developing these technologies, efforts must be made to address numerous ethical and legal challenges. A neglected problem has long been how to understand and process environmental perception data from the sensors referring to the cognitive psychology level of the human driving process. Cognitive computing ability is another challenge in vehicle driving to remedy older people's cognition driving style. Significant changes in the elderly cognitive principles and public policy are needed to regulate vehicle automation to advance the field of vehicle automation as a safety aid of the future.

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