



Exploring Japan's older adults mobility challenges and the potential role of autonomous vehicles

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ABSTRACT

Mobility is essential for maintaining human well-being, as it aids in accessing basic needs and engaging in social activities. For older adults who drive, driving provides a sense of independence and convenience, allowing them to go wherever and whenever necessary. However, the declining physical condition and cognitive functions of older adults may eventually hinder their ability to drive safely. In Japan, many older drivers prefer to continue driving unless they are officially deemed unfit, reach a certain age, or have someone drive for them. To shed light on the mobility challenges faced by Japan's older adults, we analyzed data from the Japanese Study of Aging and Retirement (JSTAR) survey using exploratory analysis methods such as multiple correspondence analysis (MCA) and nonparametric tests. The results revealed relatively strong relationships between car ownership and self-rated health status, the number of years lived in the current municipality, and the working status of older adults. Furthermore, we identified a higher level of independence, as well as a positive attitude and tendency to give and receive help running errands, among older adults who own at least one car. To assist older drivers in maintaining their mobility and the positive social effects associated with car ownership, this study discusses the potential role of autonomous vehicles (AVs). Specifically, we support the car-sharing business model to lower the financial commitment of older Japanese drivers while providing access to this technology.

1. Introduction

For older adults who drive, driving provides a sense of independence. It is also a part of their well-being maintenance. Driving continues to give them the convenience of accessing places for their daily necessities, healthcare, and social interactions, despite dramatic changes that are taking place in other parts of their lives due to aging and retirement (e.g., declining cognitive functions and changes in social roles). Studies indicate that ceasing driving for older adults causes a significant decline in mobility. Such mobility decline, in turn, may cause an increase in physical and mental health risks. [Nikkei Asia, 2021](#) and [SAE International, 2021](#) reported that losing a driver's license negatively affects older adults' health, mobility, safety, independence, and quality of life. Furthermore, the effects are not limited to themselves; the children of older adults also worry about the responsibility they would have to undertake once their parents stop driving ([Rosenbloom, 2010](#)).

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Counterintuitively, studies have shown that providing better access to alternative transport modes cannot sufficiently compensate for the mobility challenges caused by ceasing driving (Haustein & Siren, 2014; Ichikawa et al., 2016). While a German study showed that the main travel purpose of older adults is to access healthcare, food shops, post offices, and other cultural, social, and leisure facilities (Bakaba, 2010), the transport needs of older people are not homogenous. Their needs vary and can be affected by many factors, such as lifestyle and sociodemographic characteristics. For example, older adults who are still working have different travel needs than those who have retired. Similarly, those living in a detached house have different travel needs than those living in a communal elderly care house. Heterogeneity in travel needs is also observed among various ages, gender, income, possession of a driving license or lack thereof, and household size (Cui et al., 2017; Hildebrand, 2003). Moreover, it is found that ‘serious’ transport requirements such as healthcare and citizen administrative duties may be provided by alternative means. However, the ‘discretionary’ trips that contribute significantly to the quality of life, such as visiting friends and relatives, as well as leisure activities, may be lost when private transport is unavailable (Davey, 2007).

Among older adults, only those who have used public transport throughout their lives are usually more open to considering various transport alternatives (Shrestha et al., 2021). On the other hand, those who have always used cars as their main mode of transport are hesitant to take public transportation for various reasons, such as unfamiliarity with the system, physical challenges to using the system, inconveniences such as bus stop location and waiting time, and unfriendly drivers (Luiu et al., 2018; Shrestha et al., 2021). Particularly in Japan, older adults are worried about causing disruptions to busy younger passengers (Sakakibara, 2012).

Given the limited success of public transportation in providing travel alternatives for older adults, many of those aged above 75 choose to move to cities where health services and living amenities are more accessible due to the higher population density (Kim & Han, 2014). The trend is observable in at least two of the most rapidly aging Asian countries (World Economic Forum, 2023): South Korea (Kim & Han, 2014) and Japan (Takahashi, 2022).

To accommodate the challenges faced by older adults, artificial intelligence (AI) and the Internet of Things (IoT) have been explored and implemented in various technologies. Healthcare is among the most popular areas for such implementation, as aging comes with increased health ailments and medical needs. Remote healthcare is one prominent example of such development (Alshamrani, 2021). However, actual users of such services sometimes want to maintain their social networks in places outside their homes and would rather enact “active aging” (Aceros et al., 2015). There are also limitations to what a remote healthcare system can provide. For example, some patients with advanced diseases must still be treated at the hospital (Matsubara et al., 2016), which makes a trip to the hospital necessary. Moreover, a multinational Asian study suggested that people over 65 and retired should be encouraged to immerse themselves in face-to-face social interactions, such as volunteer work, as it is critical for well-being enhancement (Huang, 2019). Therefore, it is important for older adults to remain mobile despite the mobility challenges they may face.

To understand the mobility challenges and circumstances faced by Japan’s older adults, we performed an explorative analysis on the attributes of older adults from the Japanese Study of Aging and Retirement (JSTAR) survey database. With 30% of the Japanese population aged 65 and over (Statistics Bureau, 2021), and the automotive industry being one of Japan’s core industries (JAMA, 2020), Japan has the potential to set a global example on how automotive technologies can evolve to support the mobility of older adults. Using the same database, we also analyzed the following mobility-related concerns: 1) difficulty in using public transport; 2) ability to independently go to essential places; 3) perceptions about receiving mobility help from other people; and 4) willingness to help others with mobility challenges.

This study also examined the possibility of autonomous vehicles (AVs) as an aid for older drivers to maintain their mobility. To do so, the findings from the analyses in this study are compared with previous literature focusing on the intersection between older adults and AVs. Comparison of the results are categorized as strengths, weaknesses, opportunities, and threats (SWOT).

2. Literature review

This literature review section is organized as follows. First, we discuss the mobility challenges among older adults in Japan. Second, we summarize the regulatory and technical strategies that have been implemented to address the challenges. Finally, we review international studies on the intersection between older adults and autonomous vehicles, followed by a summary of surveys on Japan’s public perception of AV use to aid older adults’ mobility challenges.

2.1. Mobility challenges among older adults in Japan

Several studies investigating the common belief that older drivers are posing a risk to themselves by continuing to drive have been conducted in Japan. A study among occupational truck drivers in Japan by Hamido et al. (2021) found that older drivers do not necessarily have a higher risk of accidents than younger drivers. The study argued that more serious accidents are determined by the number of miles driven, obesity, and lack of sleep. Another study by Sakakibara (2012) also argued that while it is true that the number of car accidents involving senior citizens is increasing, it is partly a reflection of the rising population of older adults and the increased percentage of older adults among drivers in Japan. Therefore, he concluded that age alone is not enough of a reason to discriminate against older adult drivers.

In line with the notion that mobility is a significant factor in maintaining the well-being of the elderly, Lin & Cui (2021) and Kitagawa (2015) found that many Japanese older adults who drive have higher levels of mobility and more frequent social participation, which contribute to their health. These findings highlight the importance of mobility for the health of older adults. Kitagawa (2015) also argued that the declining mobility caused by cognitive impairment should be recognized as a new problem in preventive health care for older adults. Indeed, lack of mobility may lead to not only deterioration in physical health, but also mental health. Kino

et al. (2021) found that depression among older Japanese individuals is usually caused by disability and self-rated poor health.

The desire to remain active and mobile is not merely to maintain health but also due to financial needs. Although Japanese older adults are commonly believed to be wealth abundant, this may not entirely be true. Sakakibara (2012) showed that this misconception is possibly caused by the overvalue of the common assets owned by the elderly, which is usually a small plot of land. This might have been falsely reflected as high standards of living by Gross Domestic Product (GDP) per capita figures (Sakakibara, 2012). Japan is not an exception regarding lower income and expenditure among retired older adults (Pannhorst & Dost, 2019). Therefore, many older adults in Japan still hope to be active and to continue working beyond retirement age. This means that those beyond retirement age still have high mobility needs.

Moreover, having older adults back in the workforce could be good for the Japanese economy because 1) the country is facing extreme population decline (OECD, 2022), 2) it has difficulty increasing its birth rate (Nomura et al., 2019), and 3) it is struggling to attract immigrant workers (Okamoto, 2021). Many Japanese women choose not to have children or to have children at a later age due to economic burden, childcare burden, difficulties in combining childcare with a career, and differing values between the sexes (Iijima & Yokoyama, 2018). At the same time, migrant workers are recently finding Japan to be a less attractive destination due to the unfavorable treatment of immigrants and stagnant pay over the last couple of years (Okamoto, 2021). The proportion of immigrants in Japan has been consistently low at 1 to 2 percent for decades (Igarashi & Nagayoshi, 2022), and the COVID-19 pandemic has only worsened this situation with rigid border controls (Okamoto, 2021). Therefore, if the Japanese older adults are to be actively recruited into the workforce, their mobility needs will also be highly important.

In Japan, there is no age limit at which a person must give up their driver's license. Holders of driving license must renew their license regularly, every five years if they renew it at age 69 or younger and every three years if they renew it at age 71 or older. The license will be valid for four years when they renew it at the age of 70. However, if the drivers have committed a traffic violation before renewal, the license will only be valid for three years (Ichikawa et al., 2016).

Although the elderly is still legally permitted to drive, a study in Ibaraki Prefecture shows that reaching a certain age is a factor that affects one's decision to cease driving, along with being advised to quit driving and having someone to provide rides when needed (Ichikawa et al., 2016). The study also revealed that the availability of public transportation is not a determinant of the cessation of driving among Japanese older adults. Instead, the reluctance to take public transportation among them is influenced by several factors, including the complexity of bus routes and schedules, the differing pace of movement compared to younger passengers, and the limited availability of seats in buses. For long-distance travel, railroad stations and airports are also challenging for older adults due to long walking distances and a shortage of resting benches. Moreover, connections between different modes are confusing even for younger passengers (Sakakibara, 2012).

Fortunately, long-distance travel is not particularly a necessity for many older adults. (Bakaba (2010)) argued that the average trip lengths per day made by older adults are usually shorter than those made by younger groups, especially because of the reduction or removal of work-related trips. In city centers, facilities for daily necessities, healthcare, and social interactions are usually accessible within walkable distances. Urban agglomeration is also the main reason for older adults to move to cities (Takahashi, 2022).

While walking is generally advisable for older adults due to health reasons, longer-living older adults are at the limit of their functional capacities, with more diseases and poorer health (Krug et al., 2016). Those who are fit and do not own motorized vehicles or bikes tend to walk and exercise more. However, the decision to walk is largely influenced by the availability of road safety, aesthetics, and the nonexistence of steep roads (Tsunoda et al., 2012). Beyond walking distance, Japanese older adults who have ceased driving are faced with mobility challenges.

The mobility challenges faced by older adults may be exacerbated given the decreasing trend in the co-residency of older adults and their adult children. Not too long ago, cross-generational co-residency was still valued in Japan (Takagi & Silverstein, 2016). However, recently, many younger and older generations have chosen to live separately (Yang et al., 2022). This change in value reduces the possibility of older children being expected to drive for their parents when needed.

Based on the studies outlined above, it is clear that the elderly, including those in Japan, face mobility challenges given their increasing age and declining cognitive and physical strength. Interestingly, the risk of car accidents is not associated with age. Moreover, with the large number of the elderly who wish to remain active in the workforce, in addition to the declining trend of co-residency between elderly parents and adult children, the mobility needs of Japanese elderly is increasing. The upcoming sections discuss the strategies which have been undertaken to support the mobility of Japanese older adults and the intersection between older adults and AV.

2.2. Strategies to cope with the mobility challenges of older adults in Japan

Several strategies have been introduced in Japan to help the increasing population of older adults facing mobility challenges. Sections 2.2.1. and 2.2.2. summarize the regulatory and technical strategies, respectively, as well as their outcomes.

2.2.1. Regulatory strategies

As a financial incentive, especially for those encouraged to cease driving, discount fares or free mass transit passes are offered to senior citizens aged 65 or older (Sakakibara, 2012). However, when the strategy was adopted in urban areas, the increased demand made public transport more crowded and encouraged commuters who paid a full fare to return to private transport. This phenomenon decreased public transport revenues and eventually created a great financial burden on municipalities (Sakakibara, 2012).

Another regulatory strategy was to make it mandatory for senior drivers to place an "elderly mark" sticker on the car they drove. The sticker is expected to alert younger drivers to be more careful when driving near older drivers. However, many senior drivers found

it discriminatory and refused to comply (Sakakibara, 2012).

2.2.2. Technical strategies

There are also technical strategies taking place in Japan to ease the mobility of older adults. Some of them are known as “seamless mobility,” “universal design,” and “elder welfare facilities.” “Seamless mobility” refers to improved directions and transit sign systems designed to be friendlier for older adults (Kawahara & Narikawa, 2015). Some examples are by using pictograms, larger font sizes, and placing signs at a lower height so they can be at the eye level of older adults.

“Universal design” is an initiative by the Toyota car company, where private passenger cars are designed ergonomically for older adults (Kawahara & Narikawa, 2015). Some examples are the oval-shaped steering wheel, which allows a sufficient gap between the lap of the driver and the steering wheel; improved visibility and readability of the control panel display screen; and the elimination of the central pillars on the side of the car between the front door and the sliding rear doors, which allows easier loading and unloading of wheelchairs.

“Elder welfare facilities” are dwelling complexes for older adults that include important facilities such as healthcare facilities, shops selling daily necessities, and common spaces for interaction among the facilities’ residents. The facilities have become highly popular with the increasing older adult population and the declining trend of older adults living with their grown children. However, as demands exceed the availability of such facilities, they are usually at full capacity with hundreds on the waiting lists (Pan & Fukuda, 2016).

2.3. Studies and surveys on older adults and autonomous vehicles

2.3.1. International studies on the intersection between older adults and autonomous vehicles

Outside Japan, many studies have been performed on the intersections between older adults and AV. Kovacs et al. (2020) performed a systematic review on the potential of AVs to address challenges faced by older adults’ mobility. The study listed the potential benefits of AVs in the health, environmental, economic, and social sectors. An example for each sector is better safety and air quality not only for drivers but also for pedestrians and cyclists; reductions in total traffic and costs per distance unit of travel; lower operating and car ownership costs; and the potential of new travel patterns as well as more inclusive technology designs. The study also listed the potential risks that may occur if AVs develop in the wrong direction in society, such as aggressive driving behaviors due to illusion of safety protection, worsening environmental conditions due to increased total traffic density and fossil-fueled vehicles, disinvestment in public transportation, and worsening social street value if they become a substitute for walking.

The body of literature examining the topic of older adults and autonomous vehicles can be categorized by the type of data used and the data collection methods. The first category is qualitative studies employing a small sample size, usually below 100 respondents. The second category is quantitative studies employing a large sample size, usually in the range of thousands, collected via internet surveys.

In the first category, various branches of qualitative methods are observable in the literature. An in-person interview-based study with 15 older adults in England showed that the choices respondents made between public transportation and autonomous vehicles were grounded in their need for social interaction, physical activity, perceived safety and stress levels, and the affordability of travel activities (Zandieh & Acheampong, 2021). Another interview-based study was performed in Australia, employing more respondents (63 older adults). The recruited participants are living in retirement villages where they interact with a shared autonomous vehicle (SAV). The recommendations received from the participants of the study had a stronger focus on issues relating to accessibility and the physical layout of the vehicles. Participants in this study also requested human assistance at the initial exposure to AV (Booth et al., 2022). Finally, an interview study with 10 older adults in Ireland highlighted the directions of research needed in the intersections between older adults and autonomous vehicles: 1) the social impact of AV on family relations; and 2) the impact on older adults’ deteriorated cognitive abilities on the design of appropriate AV business models (McCloughlin et al., 2018).

While the interview-based studies mentioned have revealed the needs, expectations, and requests from older adults for a desirable AV design and assistance for a smooth transition, the focus-group and enactment studies exposed the concerns that older adults may have regarding the adoption of AVs. For example, a focus group-based American study involving 39 older adults identified the participants’ concerns about the financial cost to purchase such a vehicle and the training required to operate it (Huff et al., 2019). The same group of researchers performed an enactment study that proposed an approach to diminishing the initial concerns about trust and safety toward AVs through training and repetitive successful vehicle operation (Gluck, Huff, et al., 2020). Another enactment study suggested some specific details of AV designs desired by older passengers which are: 1) assistive features to enter and exit the vehicle; 2) storage for mobility aids such as canes, walkers, and wheelchairs; 3) emergency assistance where the vehicle can detect an emergency situation and notify the right personnel without requiring user input; 4) a design that allows privacy for passengers who do not want to interact with others; and 5) a universal user interface that can assist passengers with various impairments (Gluck, Boateng, et al., 2020).

Another innovative method in the qualitative studies category is the simulation study. Since high-level AVs are still generally not commercially available, Classen et al. (2021) recruited 104 older adults to experience driving a level 4 automation (high automation level with minimum control from the driver) mode simulator vehicle. Participants were asked to report their perceptions before and after the experience. The results of the study showed that the participants’ perceptions of the safety, trust, and perceived usefulness of AVs increased after the experience.

The last observed method in the qualitative study category is a combination of telephone interviews (n = 68) and in-person focus groups (n = 56) (Siegfried et al., 2021). This American study combined the possibility of offering level 5 AVs (full automation) with a

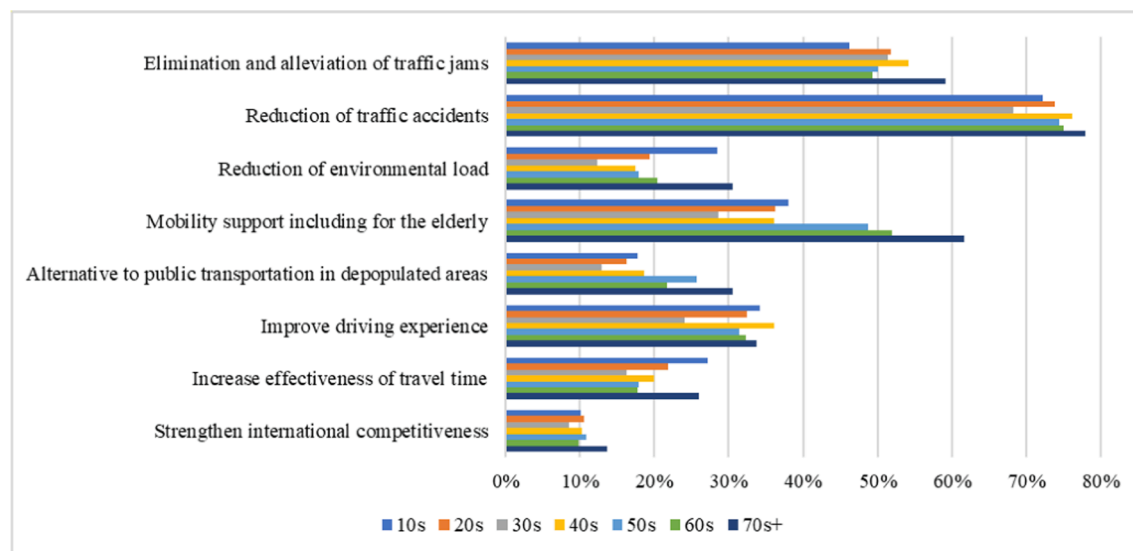


Fig. 1. Expectations for Automated Driving Systems Note: Sample size = 1089 Source: Japan National Police Agency (2016).

ridesharing business model. The study found that older adults were not willing to use the offered service due to safety and trust concerns about the technology.

In the second category of the literature body, large sample sizes recruited through online surveys are commonly quantitatively analyzed. A Canadian study using online survey data of 4,436 people aged 65 years and older showed that almost half (48.1%) of the respondents agreed that they would feel comfortable riding in an autonomous vehicle if they could intervene as needed. However, compared to younger age groups, older adults are less willing to pay more for the automation feature. Furthermore, the study found that not all respondents desired to share the car with a passenger. There were equal responses on the importance of driving alone or with passengers (Hassan et al., 2019). The same researcher performed another online survey data study of 1000 older adults in Canada and revealed that approximately two-thirds of the respondents expressed concerns about liability in the case of technical failures of an autonomous vehicle (Hassan et al., 2021).

The rest of the observed studies do not employ data exclusively from the older adult population but rather from people from all age groups to give a comparative perspective. For example, in England, a study employed an online survey of 2954 responses from people of all age groups legal for driving. The study revealed that older adult respondents are willing to use some automation but are less interested in full automation compared to younger age groups (Abraham & Reimer, 2016). Another mixed-age group study was conducted in China, employing 376 online survey responses about people's perceptions of autonomous vehicles to be adopted after their (future) retirement. The study used an ordered logistics regression model and found that those currently using alternative transportation business models such as car sharing and car hailing are more likely to use AV services. The study also employed clustering and correlation analysis and found that those living with children and living within walking distance to facilities providing their main necessities are less likely to adopt AVs (Hao et al., 2023).

Most studies in this area have approached the topic of AVs for older adults from the perspective of potential users. However, there are also a few studies that approach it from a technological perspective, such as the one done by Knoefel et al. (2019). The study highlighted the automation functions such as steering, speed control, braking, and navigation that can help with the common declining cognitive domains in older drivers, such as visual scanning, attention, speed of processing, executive function, and memory. Another study with a different perspective was the one done by Harper et al. (2016). Although not exclusively about older adults, the study estimated the potential increase in vehicle miles traveled (VMT) of older adults, nondriving populations, and those with a travel-restrictive medical condition that can be made through AV adoption. The study found that only a 14% increase relative to the current level can be achieved. One of the study's suggestions on ways to increase the results was by improving the accessibility of autonomous vehicles to older adults.

The international studies summarized in this section are mostly from Western countries such as the United States, the United Kingdom, and Australia. Furthermore, the one Asian study found (China) did not employ survey data exclusively from older adult respondents. These countries also have similar rates of older adults in their populations. In the United States, 16.8% of the population is 65 years old or older (United Health Foundation, 2023). The number is 18.6% for the United Kingdom (Office of National Statistics, 2021), 17% for Australia (Australian Government, 2023), and 18.1% for China (Hao et al., 2023). None of these countries has a rate near the rate of Japan, where 30% of its population is aged 65 and older (The World Bank, 2022). A higher rate of older adults in the population may produce different dynamics, speeds, and focuses on the automation industry. This argument is supported by a study by the Asian Development Bank that investigated the indirect impact of population age distribution on technological advances. The study found that when the share of older people increases and the working-age population decreases, there will be a decrease in economic growth. In such a scenario, automation technologies in high-technology-adoption countries might allow older age groups to contribute

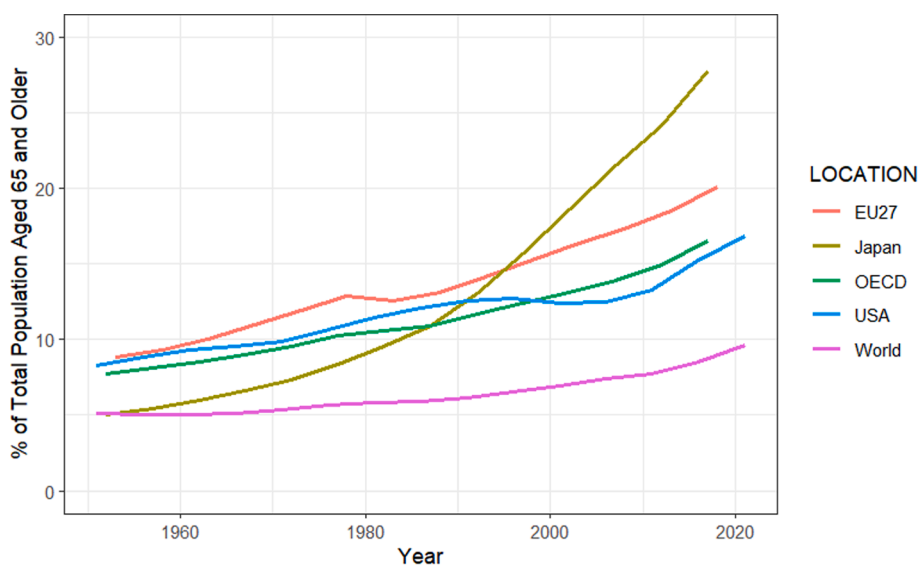


Fig. 2. Percentage of the population aged 65 and older. Source: [OECD 2022](#), modified by authors. Note: EU27, OECD, and World show the average percentage of the population aged 65 and older for 27 EU member countries, 38 OECD countries, and the world, respectively.

more positively to future growth ([Park et al., 2022](#)). With Japan's higher percentage of an older population and technological advances, the existing knowledge body would benefit from a Japanese perspective on this topic.

2.3.2. Existing surveys about the potential use of AV to address Japan's older adults' mobility challenges

Several surveys have been conducted to see how the Japanese perceive and anticipate the introduction of AVs in the market. The surveys were conducted by various institutions, such as a car rental private company ([Park24, 2018](#)), a software developer company ([Marketing Research Camp, 2016](#)), an insurance company ([Sompo Holdings, 2020](#)), the national police agency ([National Police Agency, 2016](#)), and a collaboration of ministries with an insurance company ([Daiichi life research institute, 2021](#)). Although the respondents of all these surveys are from various age groups, there are some interesting outputs that are noteworthy: 1) over half of the Japanese respondents expressed their willingness to use an AV ([Park24, 2018](#)), 2) most respondents are positive about the potential role of AV to support the mobility of older adults ([Marketing Research Camp, 2016](#)) ([National Police Agency, 2016](#)), and 3) a demonstration video about AV improves positive expectations toward the technology ([Daiichi life research institute, 2021](#)). Other than the limitation of using a mixed age group of respondents, these surveys are also limited in the way the respondents were selected. Most respondents were recruited on a convenience basis, such as the car-sharing club members or clients of the insurance company that performed the survey. These limitations created a limited applicability of the results to the general population.

Perhaps the most relevant domestic survey to the topic is the one done by the Japan [National Police Agency \(2016\)](#), which shows that more than 50% of respondents aged 60 or older and more than 60% of respondents over the age of 70 expect autonomous vehicles to be helpful for their mobility ([Fig. 1](#)). The same survey also revealed that 77% of respondents who have been involved in a car traffic accident expect AVs to be able to reduce the occurrence of traffic accidents.

3. Materials and methods

Japan is well beyond many other countries in terms of its speed and magnitude of demographic aging ([OECD, 2022](#)) ([Fig. 2](#)). Japan's population aged 65 and older already exceeded a quarter of its total population at 30% in 2021 ([The World Bank, 2022](#)). [McCurry \(2015\)](#) argued that Japan would become a model for other countries in facing their demographic time bombs. While it is inevitable that the world will eventually face a similar demographic transition ([McCurry, 2015](#)), this does not have to be perceived as something negative. [Scott \(2021\)](#) claimed that the demographic transition has turned into a longevity transition. It has become increasingly necessary to make efforts to reap longevity benefits. In the area of mobility, the automotive industry contributed 62.3 trillion JPY (18.8%) in 2018 to the Japanese economy, making it the country's core industry ([JAMA, 2020](#)). These factors make Japan a great case-study country for the topic of AV role in addressing older adults's mobility challenges.

The present study utilizes a Japan-wide survey on the older adult population called the Japanese Study of Aging and Retirement (JSTAR). First, we analyzed the JSTAR datasets using multiple correspondence analysis (MCA) to identify correlations between the respondents' socioeconomic attributes, such as a selection of health conditions, level of activeness, household structures, car ownership, and savings. Then, the identified correlations are tested with a nonparametric method, the chi-square test, and Cramer's V ([IBM, 2022](#)), to determine whether the correlations are significant and strong. Furthermore, we visualized respondents' responses on their ability, perception, and willingness to help others run errands in times of illness against the status of their car ownership. The identified correlations provide insights into the mobility needs and challenges of older adults. To understand what roles AVs can play

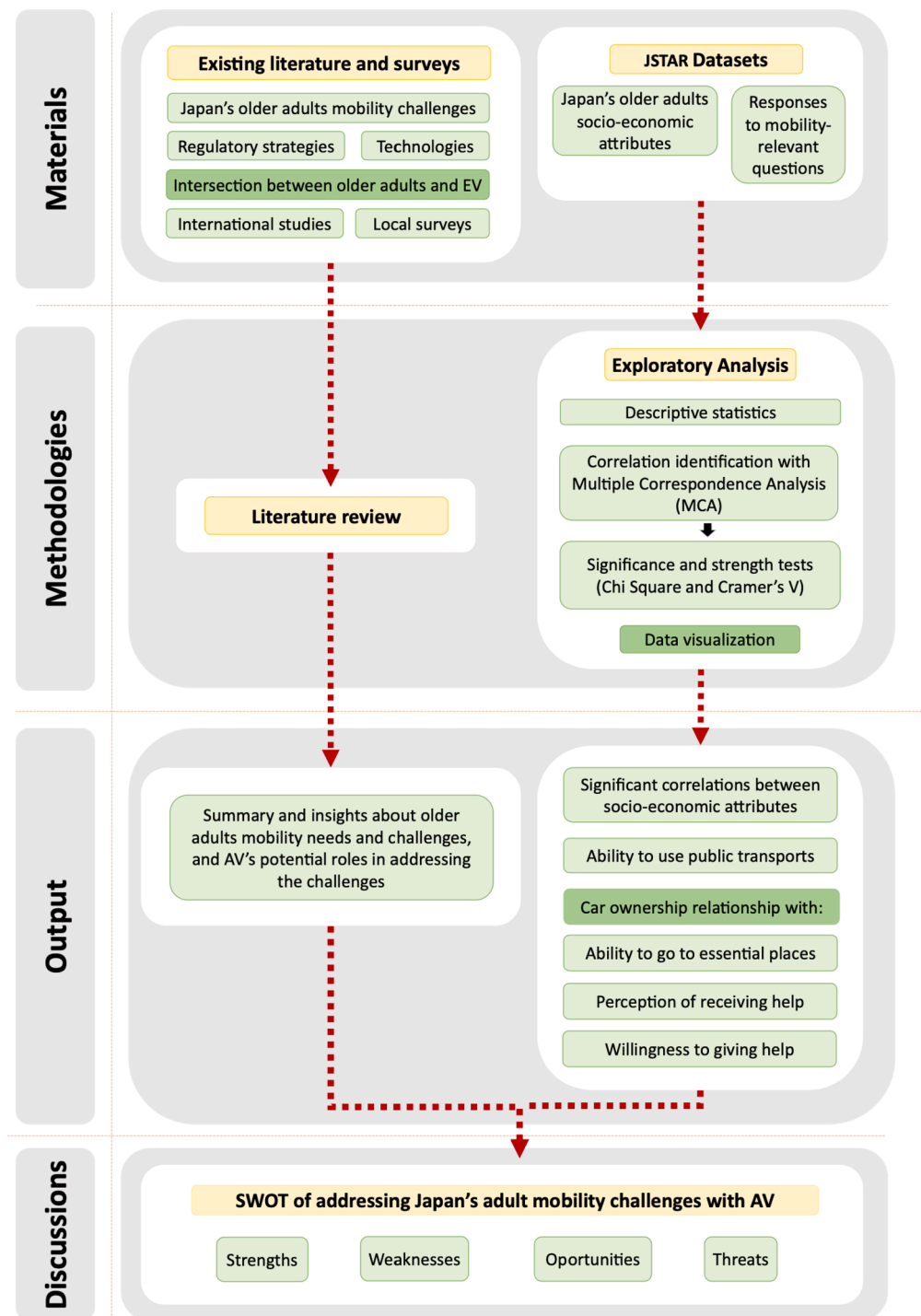


Fig. 3. Methodological framework. This study analyzes the literature and surveys with quantitative and qualitative approaches to identify the strengths, weaknesses, opportunities, and threats of addressing older adults' mobility challenges with AVs.

in addressing Japanese older adults' mobility challenges, we revisited the literature review section and compared it to our quantitative findings. The results are summarized as strengths, weaknesses, opportunities, and threats (SWOT) in the discussion section. Fig. 3 summarizes the methodological framework of this study.

Table 1
Basic social attributes of the respondents.

Variable	Obs.	Mean or (%)	Std. dev.	Min	Max
Age	4936	67.280	7.350	49	82
Gender					
Male	2391	48.44%			
Female	2545	51.56%			
Working Status					
Working	1857	46.290			
Temporarily not working	45	1.120			
Not working	2105	52.470			
Do not know	3	0.070			
Refused to answer	2	0.050			
Spouse Age	3878	67.017	8.513	31	91
No. of Children	4784	1.894	1.023	0	5
Last year's income (yen)	2689	2,100,000	1,680,000	0	8,000,000
Spouse's income last year (JPY)	1662	1,720,000	1,640,000	0	8,000,000
Monthly spending excl. housing and durables (JPY)	2974	160,000	82,309	0	350,000
Monthly spending on durables excl. automobiles (JPY)	3656	50,581	84,972	0	450,000
Savings (JPY)	2318	6,050,000	7,950,000	0	40,000,000
Spouse's savings (JPY)	4918	1,030,000	3,680,000	0	30,000,000
No. of automobiles owned	3012	1.637	0.939	0	12
Years between automobiles purchase	2474	9.214	3.064	0	23
Spending on automobiles (JPY)	2416	1,650,000	817,000	0	4,000,000
Years lived in current municipality	3861	36.431	19.594	0	83
Total weekly commuting time (mins)	1585	45.519	56.667	0	900
Current health status					
Very good	181	4.850			
Good	1044	27.970			
Relatively good	2087	55.910			
Poor	351	9.400			
Very poor	40	1.070			
Do not know	30	0.800			

3.1. The JSTAR dataset

This study utilizes the fourth wave (2013) of the JSTAR dataset, which includes individual-level data on the economic, social, and health conditions of middle-aged and older adults (defined as those aged 50 or older by the survey) across ten municipalities in Japan. The respondents are selected through stratified random sampling within ten municipalities located in various areas of Japan, including northern, central, and southern Japan. The 2013 dataset contains information on 4,937 respondents and was selected for this study as it is the most recent data released on the JSTAR English official website ([JSTAR, 2018](#)). Data were collected through individual interviews by professional interviewers. The interview response rates from each municipality ranged from 70% to 100%.

Detailed information on the JSTAR database is explained in [Appendix A](#). The shortlisted questions employed in this study are summarized in [Appendix B](#). [Table 1](#) shows the summary statistics of the variables used in this study.

3.2. Multiple correspondence analysis method

The quantitative analysis in this study is divided into three sections. First, we explore the correlations between the JSTAR 2013 respondents' socioeconomic attributes ([Table 1](#)) using the MCA method. Second, we test the identified correlations using nonparametric tests. Third, we compare respondents' answers to questions related to mobility ([Appendix B](#)) and visualize them in graphs.

The MCA methodology is an extension of correspondence analysis (CA). Using MCA, the relationship pattern between several categorical dependent variables can be observed. In this sense, the method provides a generalized view of principal component analysis (PCA) when the variables that must be analyzed are categorical instead of quantitative ([Abdi & Valetin, 2007](#)). MCA quantifies nominal or categorical data by assigning numerical values to objects and categories. It then displays objects within the same category close together and places objects in different categories far apart ([IBM, 2021](#)). The spatial proximity in the figure produced by MCA can then be interpreted as how closely objects relate to one another ([Roux & Rouanet, 2010](#)). Observing objects' relationships can provide insights into the observed data ([Pandyaswargo & Abe, 2014](#)). MCA can help reveal relationships that usually only occur after a series of pairwise comparisons of variables ([Tian et al., 1993](#)). The methodology can bypass this process by displaying joint graphics produced by the multivariate treatment of data containing unknown structures ([Ayele et al., 2014](#)). The detailed walkthrough of the MCA operation using R programming employed in this study is explained in [Appendix C](#). The strength of the MCA methodology has made it popular in various fields, such as public health ([Ayele et al., 2014](#)), neuroscience ([Rodriguez-Sabate et al., 2017](#)), art informatics ([Paling, 2007](#)), and energy systems design ([Pandyaswargo et al., 2022](#)). However, relying on visual observation on the graphic results of the MCA cannot determine the statistical significance or strength of the relationships between objects. Therefore, we employ nonparametric tests such as the chi-square test and Cramer's V value after performing MCA to serve those purposes.

Table 2
Respondents' attributes and categorical frequencies.

Attributes and responses	Obs	Unit	Categories (ranges), frequencies		
			1st category	2nd category	3rd category
Age	4924	years	Low (<=62)	Med (>62, <=67)	High (>67)
Gender	4948		Female	Male	
Working status	4926		No (No, temporarily not working)	NA (Do not know, refused to answer, No answer)	Yes (Working)
Spouse age	1588	years	Low (<=62)	Med (>62, <=67)	High (>67)
Number of Children	4926		Low (0)	Med (1,2)	High (>=3)
Household Income	4926		Low (<700)	Med (>=700 and < 3,000)	High (>=3,000)
Monthly Expenditures	4926	JPY thousands	Low (<80)	Med (>=80 and <180)	High (>=180)
Household Savings	4926	JPY thousands	Low (<3,340)	Med (>=3,340 and < 7,000)	High (>=7,000)
Car ownership	4926	years	Low (0)	Med (1)	High (>=2)
Car purchase frequency	4926		Low (>=10)	Med (>1 and < 10)	High (<=1)
Expenditure on cars	4782		Low (<1,600)	Med (>=1,600 and < 2,000)	High (>=2,000)
Living duration	4926	years	Low (<= 6)	Med (>6 and <=28)	High (>28)
Weekday's weekly commute	4926	minutes	Low (<=60)	Med (>60 and <=120)	High (>=120)
Self-rated health status	4926		Low (Poor, Very poor)	Med (Relatively good)	High (Good, Very good)

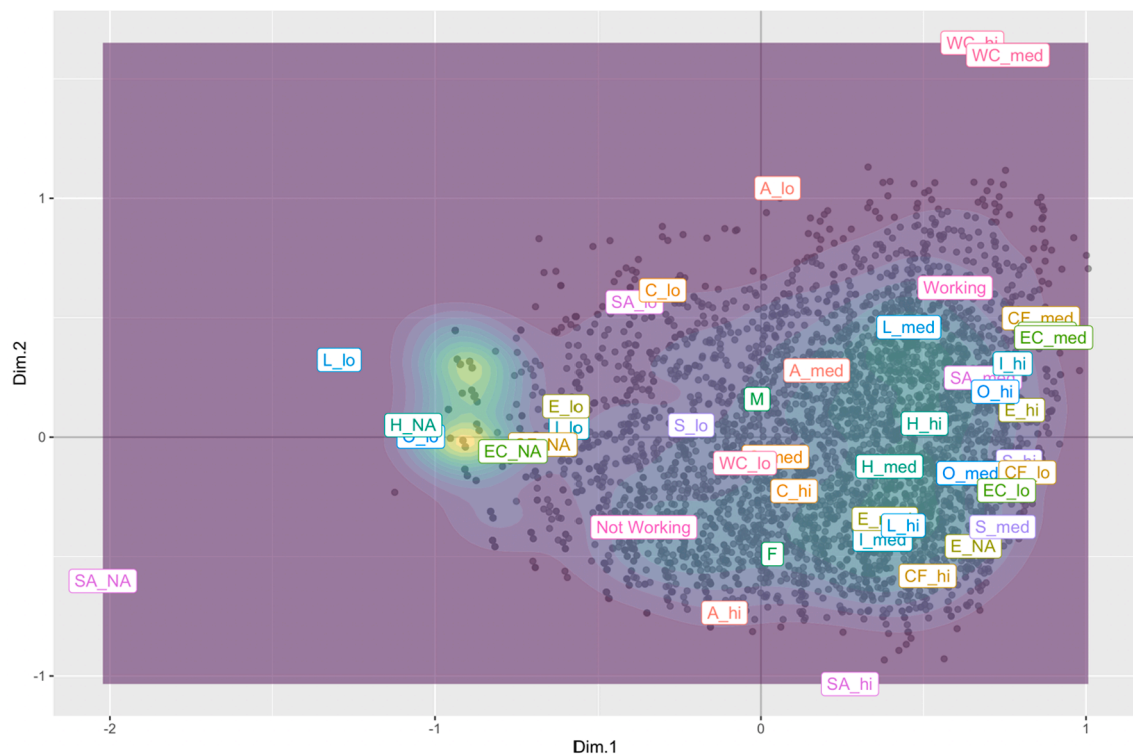


Fig. 4. MCA plot between respondents' attributes A: Age, G: Gender, W: Working status, SA: Spouse age, C: Number of Children, I: Household Income = Personal + Spouse, E: Expenditures = Durables and Nondurables, S: Savings = Personal + Spouse, O: Car ownership, CF: Car purchase frequency, EC = Expenditure on cars, L: Living duration, WC: Weekday's weekly commute, H: Self-rated health status. The most populated and strongest relationships are observed at the bottom right-hand side of the figure.

3.2.1. Preparation for multiple correspondence analysis

Respondents' attributes are categorized into groups mostly guided by their frequency quartiles or the scale of answer options (Table 2). The grouping helps to simplify the interpretation of the output. Certainly, there are unlimited ways of categorizing the responses, but we made use of quartiles as we found them to be effective in our previous MCA studies (Pandeyaswargo et al., 2022;

Table 3
Identified significant relationships.

Cross table parameters with significant chi-square test p value	Test results			
	Chi-Square	Cramer's V	Expected Count (RowParameter_category/ ColParameter_category: count)	Count
Working status * Car ownership	<0.001	0.349	W_working/O_hi: 492	768
Working status * Car purchase frequency	<0.001	0.247	W_working/ F_lo:587	753
Working status * Expenditure on cars	<0.001	0.293	W_working/ EC_med: 331	471
Working status * Weekday weekly commute	<0.001	0.301	W_working/ WC_hi: 32	82
Spouse age * Car ownership	<0.001	0.227	SA_lo/O_lo: 1000	1360
Household income * Car ownership	<0.001	0.262	I_hi/O_hi: 347	512
Household income * Car purchase frequency	<0.001	0.211	I_hi/F_med: 169	269
Household income * Expenditure on cars	<0.001	0.256	I_hi/EC_hi: 49	90
Expenditures * Car ownership	<0.001	0.283	E_lo/O_lo: 969	1418
Expenditures * Car purchase frequency	<0.001	0.216	E_hi/F_lo: 154	264
Expenditures * Expenditure on cars	<0.001	0.236	E_hi/EC_hi: 44	85
Living duration * Car ownership	<0.001	0.412	L_med/O_med: 392	569
Living duration * Car purchase frequency	<0.001	0.296	L_med/F_med: 149	215
Living duration * Expenditure on cars	<0.001	0.320	L_med/EC_hi: 43	68
Self-rated health status * Car Ownership	<0.001	0.346	H_hi/O_hi: 517	686
Self-rated health status * Car purchase frequency	<0.001	0.253	H_hi/F_med: 252	333
Self-rated health status * Expenditure on cars	<0.001	0.279	H_hi/EC_hi: 73	103

Pandyaswargo & Abe, 2014). For example, respondents aged 62 and below represent the first quartile of the respondents and are categorized as “Low”, respondents aged 62 to 67 are in the second quartile and are categorized as “Med”, and those aged above 67 are in the 3rd quartile and are categorized as “High”. Consequently, the MCA outputs are valid as far as the assumed categories are concerned.

3.3. Shortlisted questions from the JSTAR datasets

In this study, we also analyze the relationship between older adults' car ownership and 1) their independence of mobility, 2) their perceptions of receiving help when facing mobility challenges, and 3) their willingness to help others run errands when they are sick. Actual questions about these matters are listed in [Appendix B](#).

4. Results

The quantitative results of this study are presented in two sections. First, the MCA output ([Section 4.1](#)) presents insights into the identified relationships between respondents' attributes. The second section ([Section 4.2](#)) illustrates the relationship between car ownership and respondents' responses to questions about their ability to perform essential activities, their perceptions of other people's willingness to help, and their willingness to help others.

4.1. Multiple correspondence analysis outputs

The MCA output is shown in [Fig. 4](#). Areas filled with lighter colors indicate a stronger relationship among the indicated attributes, and the number of black dots represents the concentration of populations matching these relationships. It can be observed from the figure that the most populated and strongest relationships are located at the bottom right-hand side. The concentration surrounds the “L_hi” attribute, which represents individuals living in the same prefecture for more than 28 years. Attributes that are in closer proximity to those living more than 28 years include medium household income (I_med), savings (S_med), expenditure (E_med), medium self-rated health status (S_med), and high frequency of car purchases (CF_hi). For a more detailed observation, MCA graphs

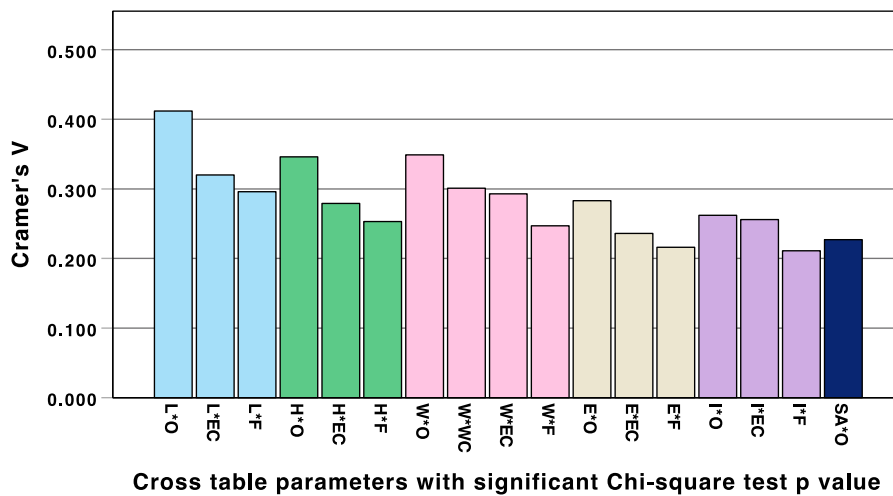


Fig. 5. Significant correlation variables with Cramer's V effect sizes. L: Living duration, H: Self-rated health status, W: Working status, I: Household income, E: Household expenditure, SA: Spouse age, O: Car ownership, EC: Expenditure on cars, F: Car purchase frequency, WC: Weekday weekly commute.

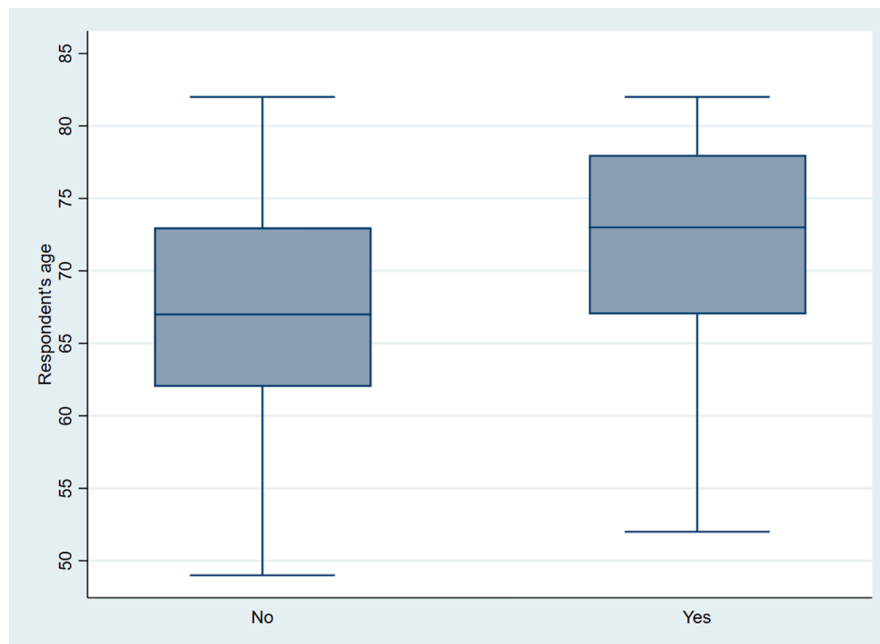


Fig. 6. Had difficulty using public transport by age.

composed of fewer attributes are presented in [Appendix D](#).

4.2. Significance and strength of correlations

To test the significance and strength of the relationships, a chi-square test is performed using the following cross-table arrangement based on the variables identified around the concentrated area: age, gender, working status, spouse age, number of children, living duration, household income, expenditures, and savings are set as rows. Car ownership, car purchase frequency, expenditure on cars, and commuting durations are set as columns. The results that are statistically significant with moderate and strong correlations (p value less than 0.001 and Cramer's V effect size larger than 0.2) (IBM, 2022) are summarized in [Table 3](#) and [Fig. 5](#).

According to Cramer's V results, the strongest relationships can be observed concerning parameters L, H, W, I, and E, which are living duration, self-rated health, working status, household income, and household expenditure, respectively. With living duration, car ownership has the strongest correlation (indicated by Cramer's V above 0.4). The data show that those living in the same

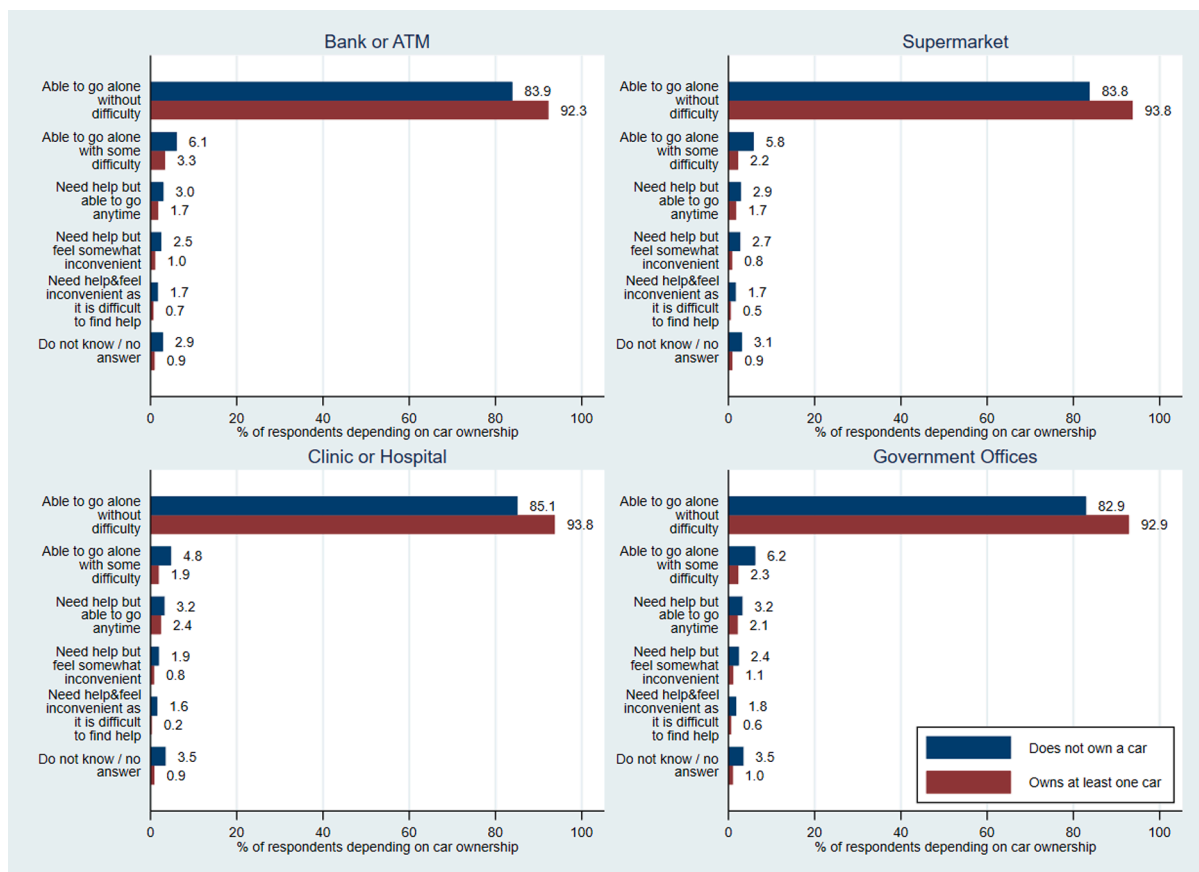


Fig. 7. Ability to independently go to essential places by car ownership.

municipality between 6 and 28 years, usually own 1 unit of car. This group also has higher and more frequent expenditures on cars. These characteristics are also closely related to higher self-rated health, active working status, higher household expenditure, and higher income. Another significant parameter observed is a higher weekday-weekly commute time for those still working.

4.3. Respondents' attributes and response comparison results

Following up on the MCA findings, where car ownership was significantly correlated with many key attributes, we analyzed the number of respondents who reported having difficulty using public transportation. The data showed that respondents who reported having difficulty using public transportation tended to be older than those who reported having no difficulties (Fig. 6).

The result above implies that car ownership (regardless of who's driving) may be a necessity for the elderly to support their mobility, as they report difficulty in utilizing public transport. Therefore, we also compared car ownership status with respondents' responses on 1) their ability to do essential activities independently (Fig. 7), 2) their perception of others' willingness to help take care or run errands when the respondent becomes sick (Fig. 8), and 3) the respondent's willingness to help take care of or run errands for others when they become sick (Fig. 9).

Fig. 7 shows that a slightly larger proportion of respondents who own at least one car report that they are able to run errands independently without any difficulty compared to respondents who do not own a car. Conversely, those who do not own any car are more likely to report higher levels of difficulties in running errands. Regarding the perception of others' willingness to help, compared to respondents with no car, those who own at least one car tend to have more positive perceptions about receiving help, especially from their spouse and family members living together (Fig. 8). More than 80% of respondents who own at least one car perceive that their spouses living in the same house will help them when they are ill. In contrast, less than 50% of respondents who do not own a car expect their spouses to do the same. When the question is reversed to whether they will help take care of or run errands for others when they become sick, those who own a car tend to be more willing to help than those who do not (Fig. 9). An interesting observation is that the proportion of respondents who report not having a spouse, children or relatives living in the same house or away, and friends or neighbors is consistently higher for those who do not own any cars (Figs. 8 and 9).

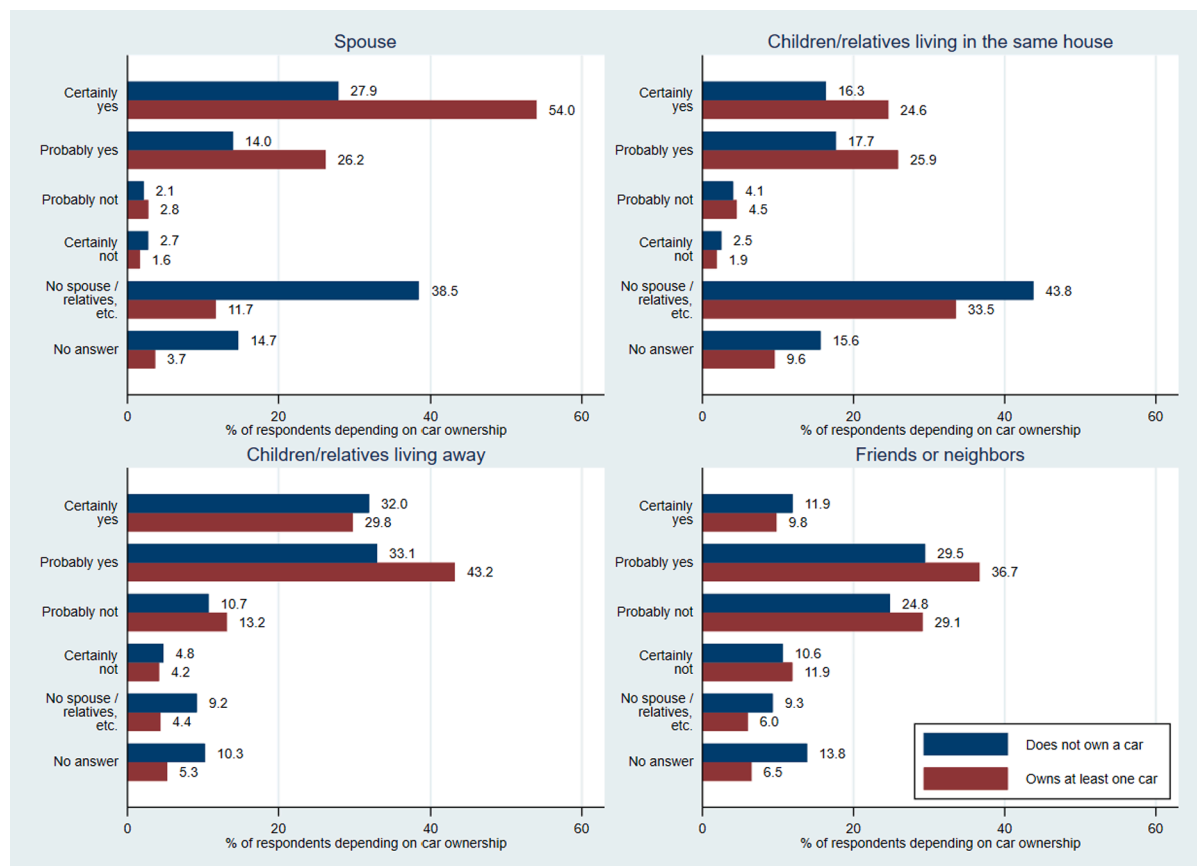


Fig. 8. Perception of whether other people will help to take care or run errands for the respondent if they become sick based on car ownership.

5. Discussions

This section discusses the main output of the quantitative analysis of this study, compares it with the literature to see how AVs may help address older adults' mobility challenges, and then summarizes them. The summary is categorized into SWOT categories to obtain a better understanding of what kind of actions should be taken by various stakeholders in older adults' mobility and AV development.

5.1. Comparison of the quantitative assessment output in this study with the literature and surveys

First, the strongest correlation found in the MCA output indicated by Cramer's V is between living duration and car ownership (Fig. 5). Specifically, those with a medium duration (6 to 28 years) of living in the same prefecture tend to have one car (refer to Table 2 and Table 3). In the literature, Takahashi (2022) revealed that older adults in Japan move to more agglomerated areas as they grew older. Similarly, Kim & Han (2014) found that in Korea, people aged 75 and above show a strong mobility pattern toward higher density areas compared to other older people. Assuming that the owned car is driven by the respondents (discussions where the car is driven by other people are presented in the next section), it can be interpreted that perhaps those who can still drive stay where they are until they cease driving at their more advanced age and then move to the more agglomerated cities that offer easier access to their daily necessities. Regarding the role of AVs, the Chinese study performed by Hao et al. (2023) found that people who live within walking distance to facilities providing their main necessities are less likely to adopt AVs. Therefore, AVs might be more useful to support those living in the countryside to maintain mobility in their living place. This holds true for Japan as its rural areas are in dire need of reducing the speed of depopulation to maintain their existence (CNN, 2023).

The second strongest correlation found is between self-rated health status and car ownership (Fig. 5). Specifically, those who rated their health as "high" or "very high" tend to have more than one car (refer to Table 2 and Table 3). In the literature, a study employing 3089 respondents aged 69 and over in Ibaraki city, Japan, mentioned that "being advised to quit" was a determinant of ceasing driving among older adults (Ichikawa et al., 2016). Specifically, the study asked whether the respondents had been advised by a relative, family member, or medical personnel to stop driving. Although the two sources of information about health differ here (self-rated in our study and determined by others in Ichikawa et al.'s 2016 study), health status seems to have a strong influence on the mobility of Japanese older adults. Focusing on health from another perspective, Kovacs et al. (2020) argued that AVs can contribute to improving the health and safety of drivers through better air quality and safer driving. This potential of AVs in improving safety is also supported

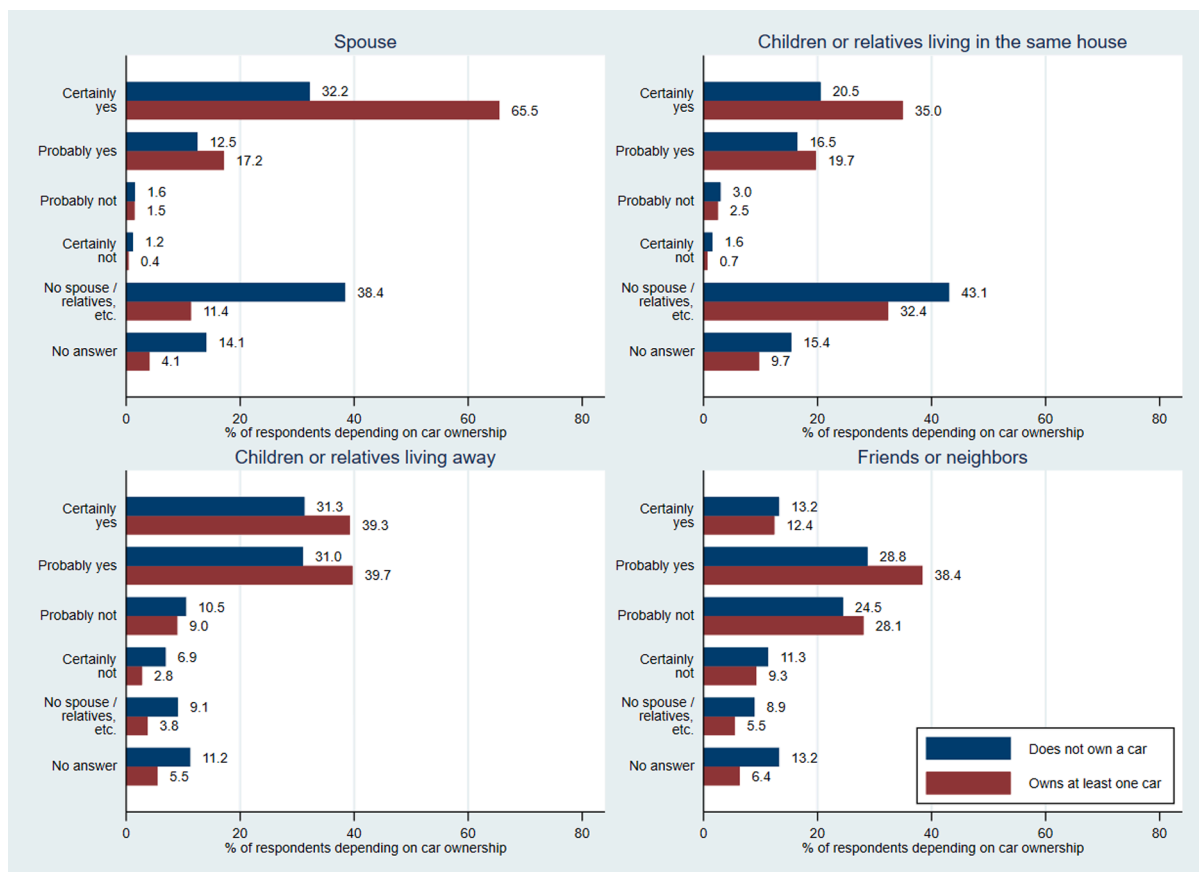


Fig. 9. Willingness to take care or run errands for other people if they become sick based on car ownership.

by the [National Police Agency's 2016](#) survey, where most people aged over 70 and people who have been involved in traffic accidents in Japan expect AVs to reduce the occurrence of traffic accidents.

Finally, the third strongest correlation is between working status and car ownership ([Fig. 5](#)). Specifically, those who still work tend to have more than one car. This relationship is also supported by other highly correlated pairs found in the data, where those who work also have a high rate of weekday weekly commute duration (more than 2 hours a week) (refer to [Table 2](#) and [Table 3](#)). The two strong correlations imply that the owned cars are most likely used by the respondents to commute to work. This finding aligns with [Bakaba \(2010\)](#), who found that work-related commuting is the major contributor to the trip duration of older adults in Europe. With many older adults in Japan wishing to remain actively working beyond their retirement age ([Sakakibara, 2012](#)), Japan's poor birth rates ([Iijima & Yokoyama, 2018](#); [Nomura et al., 2019](#)), and difficulty in attracting immigrant workers into the country ([Okamoto, 2021](#)), the importance of providing a safe, effective, and convenient means of commuting for older adults who wish to continue working is crucial. From the perspective of AV potential in extending the trip of older adults, the study by [Harper et al. \(2016\)](#) is perhaps the most relevant. The study estimated a 14% increase in VMT in older adults, nondriving populations, and those with a travel-restrictive medical condition.

The second part of this study's results that require further discussion are the relationships between car ownership and perceptions about receiving mobility help at the time of illness and willingness to run errands for others when they are ill. The results of these analyses are important because helping others is known to improve mental health and well-being, especially in older adults ([Kahana et al., 2013](#)).

Regarding the perception of others' willingness to help, those who own at least one car tend to have more positive perceptions about receiving help, especially from their spouse and family members living together. However, the development in the literature throughout the years shows a shifting trend in the practice of cross-generational co-residency. The data used in this study were collected in 2013; therefore, the results reflect the situation at that time when cross-generational co-residency was still widely practiced and valued ([Takagi & Silverstein, 2016](#)). A 2022 study by [Yang et al.](#) argued that recently, many younger and older generations in Japan have chosen to live separately. The absence of adult children who live together with their older parents might lead to more older adults continuing to drive even when it is determined that it is no longer safe to do so. [Ichikawa et al. \(2016\)](#) found that older adults are far more likely to stop driving if they are sure that someone else is available to provide a ride when they need one. The [2016 National Police Agency](#) survey showed that the strongest expectation that AVs can help older adults comes from two age groups:

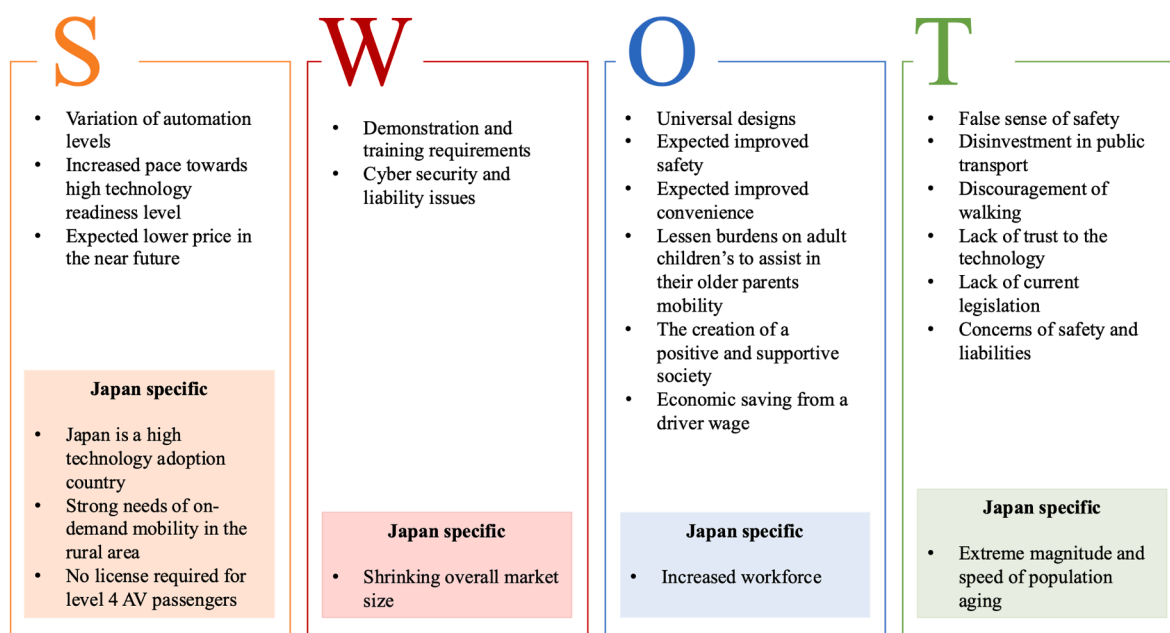


Fig. 10. SWOT table of addressing the older adults' mobility challenges with AV.

1) people over the age of 70 (0.01 significance level) and 2) people in their 30's (0.05 significance level). Since the average Japanese mothers' age of first birth is 30 (Sakai et al., 2017), it is safe to assume that those in their 30 s have older adult parents. The concerns of adult children about having to take over the driving responsibilities for their older parents have been expressed since a decade ago (Rosenbloom, 2010). Both the increasing trend of generations living separately (Yang et al., 2022) and the increasing age of first birth (Sakai et al., 2017) will place a larger hope that AV can replace adult children's responsibility to maintain safe mobility for older parents.

Finally, the result of the reversed question about whether respondents will help take care of or run errands for others when they become sick showed that those who own a car tend to be more willing to help than those who do not (Fig. 9). The relationship between these two factors is also very rarely discussed in the literature. Meanwhile, it is a valuable piece of information that may lead to finding ways to utilize technologies to improve older adults' well-being. The act of helping others has been shown to help improve mental health (Kahana et al., 2013) as it creates a sense of purpose and nurtures new and existing relationships (Mayo Clinic, 2021). Many older adults are at risk of losing their sense of purpose due to declining cognitive function and physical health, retirement, and adult children moving out of the house. Therefore, there is a potential to improve the well-being of older adults through the creation of a more positive environment where people think positively about other people and are willing to help other people, which can be gained by providing access to safer vehicles. Improved safety and convenience have been noted by several studies (Howard, 2014; Kovacs et al., 2020; Liu et al., 2019; SAE International, 2021) and surveys (National Police Agency, 2016) as something expected from AV.

5.2. Summary of the study in SWOT categories

Based on the literature review, findings, and discussions in this study, the SWOT of adopting AVs to address mobility challenges faced by older adults is summarized in Fig. 10. SWOT factors that are internationally applicable and those specific to Japan, are elaborated on in this section.

The strengths of using AVs to respond to older adults' mobility challenges lie in the various levels of control of the vehicles (SAE International, 2021). In this way, the technology can meet various cognitive needs and the desire to have certain degrees of control over driving (Abraham & Reimer, 2016). Furthermore, although some older adults are worried about the affordability of AVs (Huff et al., 2019), it has been projected that the ownership and operating costs of AVs with partial controls would be half of those of traditional vehicles by 2030 to 2040 (U.S. Department of Transportation, 2018). Moreover, although the willingness to pay for an AV is lower among older adults, those who still work spend more commuting time, are more likely to own a car, and are more willing to pay for an AV (Bansal et al., 2016).

Concerns about willingness to pay can also open opportunities for innovative business models that can make the technology more accessible. For example, some car-sharing companies in Japan (Car eco, 2022; Times Car, 2022; Toyota car sharing, 2022) have enabled users who cannot afford or do not want to deal with the maintenance side of owning a car to drive personal cars. The types of cars these companies rent vary in terms of brands, passenger capacity, machinery (combustion engine or electric), and transmission type (manual transmission or automatic transmission). Providing AVs as an option in this car-sharing service may create an opportunity for older adults to gain more exposure to the technology before committing to purchasing one if they want to. When autonomous

Table 4

Questions on difficulty performing essential activities independently.

In the past month, were you able to perform the following everyday activities without difficulty? Circle 1 to indicate “yes” if you had no difficulty, and 2 to indicate “no” if any difficulty. If an activity is not part of your daily activities, please respond based on whether or not you would be able to perform it regardless.		
Activity	Yes	No
1. Going out alone using public transportation such as buses and trains.	1	2
2. Shopping for daily necessities.	1	2
3. Making deposits in and withdrawals from your bank or postal account.	1	2
4. Visiting friends' homes.	1	2
5. Visiting sick family members, friends, etc.	1	2

Table 5

Questions on perception about other people's willingness to help.

Do you think your family, relatives, friends, etc., would take care of you and run errands for you if you get sick and become bedridden? For each category, circle the number corresponding to the answer that best describes your thoughts					
	Yes, certainly	Yes, probably	No, probably not	No, certainly not	No family, relatives, etc.
1. Spouse	1	2	3	4	5
2. Family member(s) living together (except for spouse)	1	2	3	4	5
3. Son(s)/daughter(s) living separately or relatives	1	2	3	4	5
4. Friends, acquaintances, neighbors, etc.	1	2	3	4	5

Table 6

Questions on willingness to help other people.

Would you take care of your family, relatives, friends, etc., or be asked to run errands for them if they get sick and become bedridden? For each category, circle the number corresponding to the answer that best describes your thoughts.					
	Yes, certainly	Yes, probably	No, probably not	No, certainly not	No family, relatives, etc.
1. Spouse	1	2	3	4	5
2. Family member(s) living together (except for spouse)	1	2	3	4	5
3. Son(s)/daughter(s) living separately or relatives	1	2	3	4	5
4. Friends, acquaintances, neighbors, etc.	1	2	3	4	5

Table 7

Sample cross-table of respondents' attributes.

Variables (number of categories)														
	A 3	G 2	W 2	SA 3	C 3	I 3	E 4	S 3	O 3	F 4	EC 4	L 3	WC 3	H 3
1	hi	M	Not Working	med	med	lo	lo	lo	med	lo	lo	med	lo	med
2	hi	M	Not Working	NA	med	lo	lo	lo	lo	NA	NA	lo	lo	NA
3	lo	F	Not Working	hi	hi	hi	lo	hi	med	NA	NA	med	lo	hi
4	hi	M	Not Working	med	hi	med	med	hi	med	lo	lo	hi	lo	hi
5	lo	M	Working	lo	med	hi	hi	lo	hi	lo	lo	hi	lo	med
6.....	hi	F	Working	lo	hi	hi	med	lo	med	lo	lo	hi	lo	hi

4926

A: Age, G: Gender, W: Working status, SA: Spouse age, C: Number of Children, I: Household Income = Personal + Spouse, E: Expenditures = Durables and Nondurable, S: Savings = Personal + Spouse, O: Car ownership, F: Car purchase frequency, EC = Expenditure on cars, L: Living duration, WC: Weekday's weekly commute, H: Self-rated health status.

Table 8

Sample of eigenvalues.

	Eigenvalue percentage of variance		Cumulative percentage of variance
dim 1	3.01E-01	1.45E + 01	14.54758
dim 2	1.70E-01	8.19E + 00	22.74176
dim 3	1.43E-01	6.89E + 00	29.63428
dim 4	1.01E-01	4.90E + 00	34.53294
dim 5	8.89E-02	4.29E + 00	38.82566
dim 6...0.29	8.51E-02	4.11E + 00	42.93616

Table 9
Sample of column coordinates.

	Dim 1	Dim 2	Dim 3	Dim 4	Dim 5
A_hi	-0.2264072	-0.819907	-0.4563658	0.16300772	0.01550083
A_lo	0.20027091	1.3296637	-0.6960079	-0.1907871	-0.013171
A_med	0.2308781	0.1106003	1.78538844	-0.1102942	-0.0164556
F	0.0010819	-0.358875	-0.0337481	-0.0786606	0.33871307
M	-0.0003528	0.1170224	0.01100461	0.02564973	-0.1104479
Not Working	-0.4004104	-0.3018121	-0.0141742	0.07816151	0.01520859

Table 10
Sample of row coordinates.

	Dim 1	Dim 2	Dim 3	Dim 4	Dim 5
1	0.1051495	-0.3616141	-0.2081985	-0.2624999	-0.1017814
2	-0.9160796	-0.1379603	-0.0869247	0.21136897	-0.1103862
3	0.1544438	0.3428233	-0.3131829	0.30134737	0.37115096
4	0.4850199	-0.7184017	-0.2592962	-0.3193511	0.03265654
5	0.7125028	0.4225229	-0.2905069	-0.0588546	-0.4870053
6	0.552732	-0.5071578	-0.2736427	-0.2957905	-0.1391079

vehicles are offered in this kind of shared service, users can be freed from any high initial costs, maintenance costs, and driver's wages. A typical car sharing service in Japan is paid in 15-minute increments of use, and a short duration but frequent use of the vehicle can aid the most significant weaknesses of AV adoption that should be addressed: the lack of trust in the technology (Xing et al., 2021) and the unfamiliarity of older adults with using advanced technologies (Sakakibara, 2012). The car-sharing business model can also accommodate older adults who wish for privacy when driving (Hassan et al., 2019) as opposed to the ride-sharing business model, which can serve those who wish for social interaction (Siegfried et al., 2021).

AVs are expected to improve the convenience and safety (Howard, 2014; Liu et al., 2019) of older adults who want to continue driving. However, in the coming few years, it is predicted that remote driving by a third party, including family members, will also become possible (T-Systems, 2023). Such options may increase the sense of security and lift the burden of family members who previously were prevented from joining the labor force due to the obligation of caring for older adults (Kobayashi et al., 2018). However, it also invites threats such as cybersecurity and liability issues. While such issues are common in the large-scale deployment of AI devices (Xing et al., 2021), the situation may improve when the security and regulation aspects catch up. These aspects are common parts of technology readiness development (Ihara et al., 2018). In England, the legality of remote driving is being discussed (UK Law Commission, 2023). Presently, there are no regulations for remote driving in Japan. However, panels of experts in Japan have suggested no license requirement for level 4 AV passengers (Mainichi, 2021).

AV manufacturers are recommended to design AVs geared specifically to create a convenient and safe mobility aid for older adults despite their physical and financial constraints (Gluck, Boateng, et al., 2020). Policymakers can change untrusting attitudes toward AVs through campaigns, trials, and marketing tailored to suit older drivers' mobility characteristics. AVs can also be promoted in license renewal centers. License renewal centers in Japan usually have a separate room for older drivers to refresh on driving rules and cautions. This would be a great place and opportunity to introduce AVs.

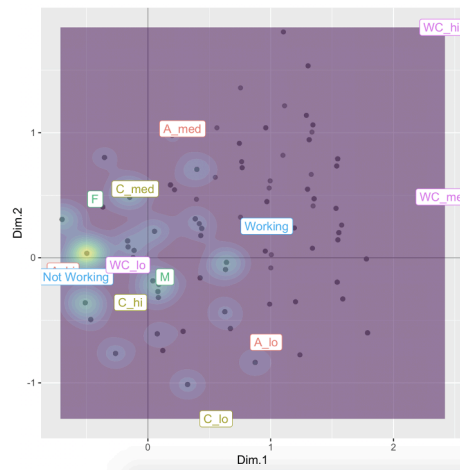
The risks of AV adoption have been listed by Kovacs et al. (2020), including the false sense of safety, disinvestment in public transport, and discouragement of walking. However, for Japanese society, the extreme rate of population aging is perhaps a more urgent concern as to whether the technology will be able to catch up with the changing needs of mobility. Therefore, managing risk factors together with technological development would be key to achieving desirable outcomes.

6. Conclusions

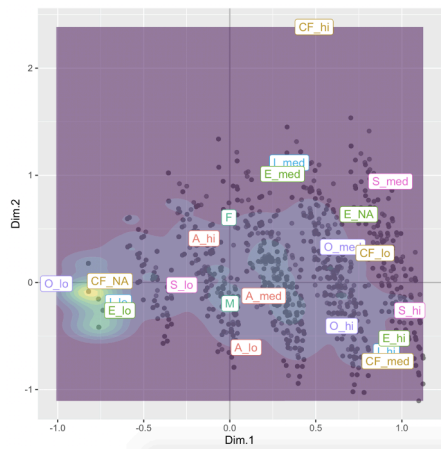
This study exploratively analyzed the Japanese survey on adults' socioeconomic attributes and challenges related to mobility. The results of the analysis were compared with literature and surveys on the interaction between older adults and AVs. The comparison output identified the SWOT of addressing older adults' mobility challenges with AVs and produced technical and policy recommendations.

The exploratory analysis results showed relatively strong relationships between car ownership and the years lived in the current municipality, self-rated health status, and the working status of older adults. We also found that those with at least one car are more likely to be willing to run errands for their spouses, as well as children and relatives, presumably due to the increased flexibility and ease of mobility of owning a car. With retired older adults' lower income and increased challenges to using public transportation, especially among those aged 65 and above, offering AVs in shared car service businesses could be practiced as a transition aid that can help the elderly familiarize themselves with the technology. Such an offering also has potential economic savings, such as from a higher initial cost, maintenance costs, and a driver's wage. Furthermore, the ownership and operational costs of AVs have been projected to be half those of conventional cars in the coming few years.

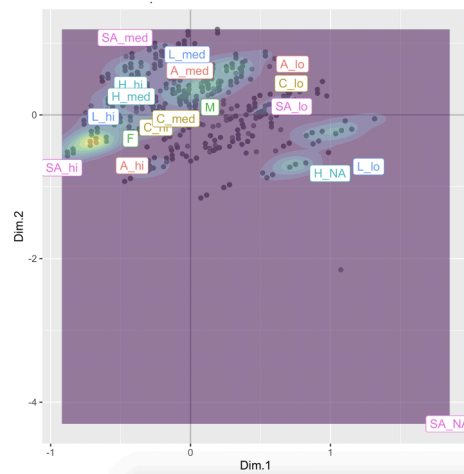
With workforce supply problems, a low birth rate, and low immigration intake, Japan must consider supporting the mobility of its



(a)



(b)



(c)

Fig. 11. MCA graphs made up of fewer attributes.

older adult population to remain active or rejoin the workforce. If AV could relieve the duties of adult children to assist their older parents' mobility, Japan may also expect more active participation from this group in the workforce. Regardless, more adult children have chosen to live separately from their parents in recent years. Furthermore, this study foresees an ideal environment to nurture well-being where older adults can independently access their needs, feel more positively about other people in their community, and are more willing to give help in the mobility aspects of their lives.

The limitations of this study can also be seen as strengths. First, the fact that it only covered the circumstances faced by older adults in Japan contributes to the research gap in the literature, which is predominantly Western. Furthermore, as Japan is a globally leading country in population aging and the automotive industry, the insights gained in this study provide knowledge about how a high technology-adoption country deals with the mobility issue of its aging population. Second, the JSTAR survey data employed in this study were not specifically designed to identify the topic of AV. However, data were collected in person instead of through online surveys commonly performed by studies with larger sample sizes in the literature. This factor is especially important for studies about older adults, where declining cognitive function is a concern. An in-person survey eliminated the concern of response inaccuracy caused by a lack of familiarity or cognitive ability in operating a computer or smartphone. Moreover, as JSTAR was designed to be comparable with other countries' survey data on aging, such as SHARE (Europe), ELSA (England), and HRS (the United States), our study has opened an opportunity for comparative studies using those survey data and the methodology demonstrated in this study to specifically reveal geographic and cultural variation influences on older adults' mobility challenges.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A

Detailed information about the JSTAR database

The JSTAR database is a panel survey conducted by the Japan Research Institute of Economy, Trade, and Industry (RIETI), Hitotsubashi University, and the University of Tokyo, Japan. The survey collects individual-level data on the economic, social, and health conditions of middle-aged and older adults, defined as those aged 50 or older, across several municipalities in Japan. The survey was designed in a way that makes it comparable with similar surveys in other countries, such as the Health and Retirement Study (HRS) in the United States, the Survey of Health, Aging, and Retirement in Europe (SHARE), and the English Longitudinal Study of Aging (ELSA) in the United Kingdom (JSTAR, 2018). The JSTAR survey was conducted in four waves: 2007, 2009, 2011, and 2013. The complete panel datasets contain answers from 7268 respondents selected through stratified random sampling within each municipality. This study employs data from the fourth wave (2013) only.

The 2013 JSTAR questionnaire contains 244 pages with approximately eight questions per page. Some of the major topics covered are "health status," "financial status," "property and assets," and "healthcare status." Because the survey itself is very extensive, we selected only questions relevant to the present study's interest, as summarized in Appendix B.

Appendix B

Tables 4, 5 and 6.

Appendix C

Descriptions of Multiple Correspondence Analyses used in this study

The functions and packages used in this study's analysis are the MCA function from the FactoMineR package in the R programming language. This study follows the MCA guidelines described in [Abdi & Valetin \(2007\)](#) and [Roux & Rouanet \(2010\)](#). The applied code was adapted from [Kassambara \(2017\)](#) and [Sanchez \(2013\)](#).

In this study, MCA is used to analyze the observed attributes of respondents. First, we categorize each of the observed attributes into several levels. Next, each level is coded as a binary variable. For example, gender is coded as "F" and "M" when there are only two levels or as "bins" if there are more than two levels. An example of the bins is "low," "med," and "high" for the number of children, specifically less than 1, 2, and more than two children, respectively. Subsequently, a sample cross-table of the categorized respondents' attributes is presented in [Table 7](#). In this scheme, a value of 3 is represented by the pattern 0 0 1. This approach ensures that each row in the MCA coding schema has the same total ([Abdi & Valetin, 2007](#)).

Since data are coded by creating binary columns and bins for each variable where only one column obtains the value 1, additional artificial dimensions are created. Consequently, the solution space's inertia (or variance) is inflated artificially. This caused a severely underestimated first dimension. To correct these effects, a correction formula (eq. (1)) is applied to eigenvalues smaller than 1 ([Abdi & Valetin, 2007](#)), where $c^{\lambda'}$ is the corrected eigenvalue, λ' is the eigenvalue obtained from the analysis of the indicator matrix, and K is the number of nominal variables. [Table 8](#) shows an excerpt of the eigenvalues.

$$c^{\lambda'} = \begin{cases} \left[\left(\frac{K}{K-1} \right) \left(\lambda' - \frac{1}{K} \right) \right] & \text{if } \lambda' > \frac{1}{K} \\ 0 & \text{if } \lambda' \leq \frac{1}{K} \end{cases} \quad (1)$$

Finally, using the corrected eigenvalues, the column and row coordinates are determined ([Tables 9 and 10](#)). The coordinates are plotted into figures and color coded using the ggplot2 package in R programming.

Appendix D

Fig. 11

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