# Shared Autonomous Vehicles:

# Preferences, Opportunities, and Future Implications

by

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# ABSTRACT

In recent years, the transformation in transportation mobility has seen an acceleration in numbers of studies establishing a sustainable, smooth and cost-efficient system by applying automated concepts to the conventional car-sharing system. The development from a personally owned vehicle-oriented scheme to shared automated transit provides us informative images to the optimal stage of the transportation mobility. The shared autonomous vehicle, which benefits from both of the features of ride-sharing services and autonomous technologies, is about to alter the automobile industry and the shape of the society at the same time. Ant it is anticipated to offer cleaner, safer, and cheaper mobility services when autonomous vehicles are finally implemented on the roads.

This study contributed to the following three main sections: 1) research on features, demand and performances studies of shared autonomous vehicles by reviewing the spotlighted studies in the field. Then, gaps and future research directions are provided for stakeholders from both business and academia side. 2) Services that provided by shared autonomous vehicles (such as child tracking, large trunk, multi-users and etc.) other than the ones from conditional taxi or ride hailing services are evaluated. The relationship between different clusters of users and their preferred services are examined. 3) The future expectation of demand and supply of shared autonomous vehicles are calculated by applying discrete choice model. In addition, the performance of shared autonomous vehicles are assessed through agent based simulation.

In the first section, the study aims to find the gaps in impacts and features, demand and performance studies of shared autonomous vehicles by a systematic approach when looking at the research aspects of car sharing in autonomous vehicles and shared autonomous vehicles. This is the first attempt to review shared autonomous studies. According to our study, emergency transportation management, flexible transportation planning and benefits to all levels of transportation modes are regarded as the potential features of shared autonomous vehicles. From the scope of demand studies, mode split analysis, before-and-after studies, users' behaviors and reduction of car ownership, preferences studies considering cross-national and gender-related studies are interesting to be explored. Moreover, combining a new transportation mode with shared autonomous vehicles and implementing new operation modes such as DRS, real-time management and private vehicle sharing scenarios could be the future research directions from the perspective of performance study of SAVs systems.

In the second section, the evaluation of people's intentions regarding shared autonomous vehicle services appears to be critical prior to the promotion of this emerging mobility on demand approach. Based on a stated preference survey in Nagoya, Japan, the preference for shared autonomous vehicle services as well as willingness to pay for these services were examined among 1036 respondents in order to understand the relationship between people's socioeconomic characteristics and their preferred shared autonomous vehicle services. For this purpose, k-modes clustering technique was selected and six clusters were obtained. Six groups with respect to different interests on shared autonomous vehicle services are clustered. The result of correlation analysis and discussion of willingness to pay on services provided insightful results for the future shared autonomous vehicle services. This study not only aids in revealing the demands of customer different clusters, but also states the prospective needs of users for stakeholders from research, policymaker and industry field, who are preparing to work on promoting shared autonomous vehicle systems, and subsequently, develops an optimum transportation mode by considering both demand and services as a whole.

Lastly, the research focuses on people's intention for use of shared autonomous vehicles as well as the ownership and shared use of their private vehicles in Meito Ward, Nagoya area of Japan. A nested logit model is established for the mode choice with person trip survey data while the multinomial logit model of autonomous vehicle ownership and shared use is developed with stated preference survey data. The former provides demand forecast for shared autonomous vehicles while the latter for the supply. Two scenarios (limited and unlimited user) are considered in this study to reflect the degree of shared autonomous vehicle acceptance in different phase. 11 - 28 % of trips will be attracted by shared autonomous vehicles based on the model. According to the agent-based simulation, 40 - 70% of the shared autonomous vehicle supply can be put on market while satisfying the expected income of shared autonomous vehicle providers. In addition, efficiency can be achieved by shared autonomous vehicles since more than 94% of the trips provided by them have waiting time lower than 1 minute.

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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **AV** | Autonomous Vehicle |
| **BK** | Buy and Keep |
| **BS** | Buy and Share |
| **CBD** | Central Business District |
| **CLARA** | Clustering Algorithm based on Randomized Search |
| **DRS** | Dynamic Ride-Sharing |
| **ER** | Easy-Reliable |
| **ESRMS** | Easy-Storage-Reliable-Multi-Shopping |
| **HI** | High-Interest |
| **ICLV** | Integrated Choice and Latent Variable |
| **IIA** | Independence of Irrelevant Alternatives |
| **i.i.d** | Independent and Identically Distributed |
| **LI** | Low-Interest |
| **MNLM** | Multinomial Logit Model |
| **NBS** | No Buy but Use Share |
| **NJ** | New Jersey |
| **NLM** | Nested Logit Model |
| **NMT** | Non-Mass-Transit |
| **PAM** | Partitioning Around Medoids |
| **PT** | Person Trip |
| **SAV** | Shared Autonomous Vehicle |
| **SAEV** | Shared Autonomous Electrical Vehicle |
| **SP** | Stated Preference |
| **SR** | Storage-Reliable |

| | |
|---|---|
| **SRMC** | Storage-Reliable-Multi-Child |
| **SSE** | Sum of Squared Error |
| **TW** | Two-wheel |
| **US** | United States |
| **V2G** | Vehicle to Grid |
| **VMT** | Vehicle Miles Traveled |
| **WTP** | Willingness to Pay |

# CHAPTER 1 Introduction

## 1.1 Background

### 1.1.1 Autonomous Technology

With the help of the autonomous technology, car manufactures and IT companies are making more autonomous vehicles for years. Start from 2009, Google launched their self-driving car projects and completed over 500,000 miles driven without incurring a crash by 2013. (Waymo, 2019). And by providing the Waymo project, Google is now providing public trail of self-driving vehicles to residents in Phoenix, AZ, US by offering emerging mobility alternatives. The development of autonomy has brought dramatic change to the automobile industry. Studies indicated that autonomous vehicles (AVs) would have significant benefits compared to conventional ones. AVs could free up drivers' travel time by offering a more intelligent, integrated system when connecting all transportation modes together. And it is foreseen than AVs will be put on market in the near future (Navya, 2018; GM, 2014; Anthony, 2014). Also, the autonomous technology can offer opportunities in urban planning, such as alleviating parking demand especially in the urban area (Burns et al. 2013). Tremendous saving lead by AVs can be categorized to crash cost, congestion cost and parking cost (Fagnant and Kockelman, 2015).

### 1.1.2 Shared Autonomous Vehicles (SAVs)

The shared economy and the autonomous technology have been much discussed and it is believed that these two factors will lead to the maturity of the mobility: shared autonomous vehicles. Jonas et al. (2015) demonstrated the four stages of mobility transformation, which Figure 1.1 (redrawn from Jonas *et al*. 2015) describes the trend in the development of the automobile industry and it presents a model of future transportation.

The figure infers a shift in people's mobility choices from the manually, personally owned pattern, to the shared, autonomy-inclined one. Within this transaction, the involvement of (1) an autonomous technology such as the Google car, or the Tesla full self-driving hardware, which has been successfully tested on several real-world environments recently, and (2) the shared economy, which the maturity of the market was proven by the installation of several companies such as Uber, Lyft, Sidecar, and etc., have dramatically stimulated the industry in terms of providing more confidence for the picture of the shared autonomy era. The transformation from (1) to (4), not only leads to more discussion in each area but also provides more valuable inferences for the study of SAVs.

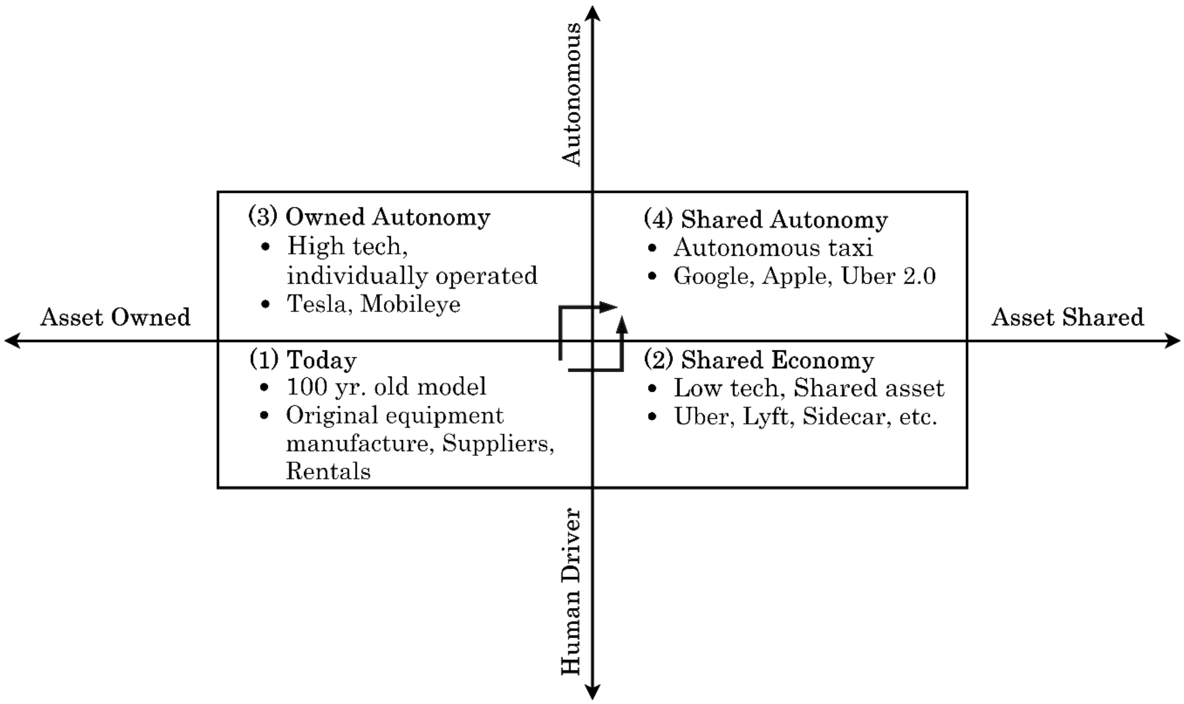



**Figure 1.1 The four stages of mobility (redrawn from Jonas et al., 2015)**

The current trend of the automobile industry and driverless technology has encouraged a tremendous amount of investigation, which provides a clear sign that driverless cars will eventually be introduced in the coming years. The SAVs services defined in this study are stated as follows: In the future, the level 4 (S.A.E, 2014) AVs owners allow their cars to move out of garages during the unused time. Afterwards, AVs can pick up passengers who make reservations and collect payment autonomously. This SAV service will provide an affordable and safer mode than human-piloted mobility services (Hao and Yamamoto, 2018).

In a description of AVs technologies, Anderson et al. (2014) stated that “shared driving” could be the first attempt mode of AVs while working on solving different tough problems including: making sense of the world around vehicles, environmental challenges, detection of sensor failure, vehicle communication, cybersecurity and cost. Therefore, we would like to look into different aspects of SAVs and expect to provide an insightful guidance to stakeholders such as policymakers, researchers and those who come from industries.

## 1.2 Aims of the study

Within the scope of SAVs, a great number of aspects could be addressed. Hardware and software engineers focus on areas such as environment detector and deep-learning algorithms for the sake of the realization of SAV moving function. Policymakers from the government side turn to legislation and urban development for better preparation of the coming of SAVs.

In this study, we describe a number of expectations that we would like to address from transportation side considering the maturity of autonomous technologies:

**Future inferences and research gaps.** Automobile industry has been worked for years on technologies to make vehicles drive autonomously such as object detection using LiDar modules and colored camera units applying deep learning algorithms. And the format of the business development when SAVs finally hit the road should be discussed. To this destination, possible research directions and the gaps are considered in this study.

**Relationship between users and SAV services.** When SAVs come to life, the preference of users ought to be considered. It would be valuable if the designated SAV services can be promoted by maximizing both the satisfaction of the users and the profit from of the car providers. To this end, users' preference on SAV services and their willingness to pay (WTP) on them were addressed by conducting stated preference (SP) survey. And the relationship between characteristics of users and features of SAV services were evaluated.

**Future market exploration and SAVs system behavior evaluation.** It is always essential get to know the potential impact of the involvement of emerging transportation. Using SP survey, the demand of using SAV services and amount of people who would like to share their personal owned AVs as SAVs were calculated. Meanwhile, in order to evaluate the future behavior of SAVs in the city, agent-based simulation was utilized to look one-step earlier at the future imagination of the condition with SAVs before the official release of the use of SAVs.

In this study, we stand at the scenario where the features of the personal-owned autonomous vehicle and characteristics of users were both evaluated. Throughout the result of this research, we are expecting that it will have positive impact on players from academic, political and commercial sides. In addition, the research relevant to the SAV has just been addressed to the stage because of the development of the AVs technology. We are hoping that this research could have insightful inferences to other researchers in similar fields.

## 1.3 Research Structure

From the following Figure 1.2, the research structure of the study is shown. The dissertation contains seven chapters. In Chapter 1 Introduction, we demonstrated the background of AVs and SAVs. The development of AV technology at present and the reason why considering SAVs as the main focus in our study were highlighted. Then, in the following section, we stated aims of the study, which three concentrations of this study were listed for better understanding of the dissertation. Also, the research structure section provided a general blueprint of this dissertation, which can be regarded as a clear guidance for the readers.

In Chapter 2 Literature Review, two sections were considered in this chapter. In the first section, studies related to autonomous technologies and SAVs in terms of features, people's preferences and performance of the vehicle system were addressed. In the second section, methodologies and tools (discrete choice model, partitioning clustering algorithms and agent-based simulation) that covered in this study were explained.

Chapter 3 introduced the general contents, source and study area of the data sets. From this chapter, readers will be able to have a better understanding of the background of the statements that proposed by the author.

Chapter 4, 5 and 6 deeply discussed different research aspects of this study. 1) Inferences and research gaps of SAVs, 2) people's preferences and WTP on SAVs services, 3) analysis considering household vehicle ownership and shared us, were demonstrated separately in theses chapters.

Finally, conclusions and inferences to the future work were demonstrated in Chapter 7. It is possible that we have limitations and incomplete considerations in our study. In this case, we would like to address these concerns and open to further discussion with other researchers who have interests in relevant fields.

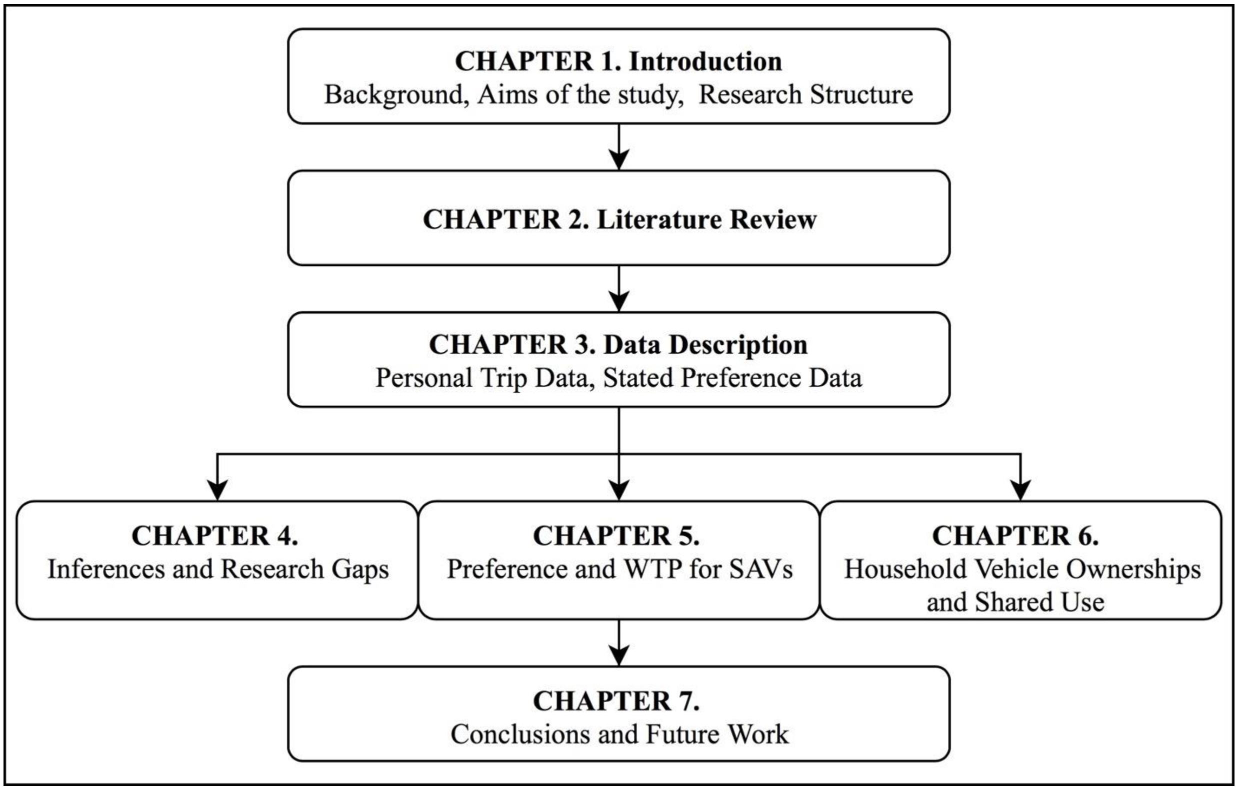



**Figure 1.2 Structure of the dissertation**

# CHAPTER 2 Literature Review

Two main sections are stated in this chapter: the first section focuses on features, people's preferences, and performance of autonomous technology and SAVs. In this part, we review a great number of studies that has contributed in relevant research fields to construct a clear framework according to the existing research results. And in the latter part, discrete choice model, partitioning clustering algorithms and agent-based simulation are introduced. We try to provide readers insightful inferences by explaining our methodologies and tools explicitly.

## 2.1 Autonomous Technology and Shared Autonomous Vehicles

### 2.1.1 Introduction

Car sharing, AVs and SAVs are all emerging transportation modes that lead to a less congested, and more environmentally friendly and efficient world. However, car sharing only benefits from its sharing mobility whereas AVs might be used for longer vehicle miles of travel (VMT) while providing in-vehicle freedom. The SAV could be regarded as a derivative form because it combines the car sharing and the AV, and lead us to imagine the transportation mode of the future. Because they absorb features from both the car-sharing system and AVs, SAVs could be seen as efficient, environmentally friendly, and cost-saving while providing a safe and comfortable service. This novel business plays an important role in a sustainable transportation system while facilitating multimodality (Krueger *et al*., 2016).

The research flow is described schematically in Figure 2.1. By using meta-analysis when combining car sharing and AVs, the deficiencies of current studies and the future expectations of the impact-and-demand studies on SAVs were found. The future directions of the performance study of SAVs were summarized by using a systematic approach in this study.

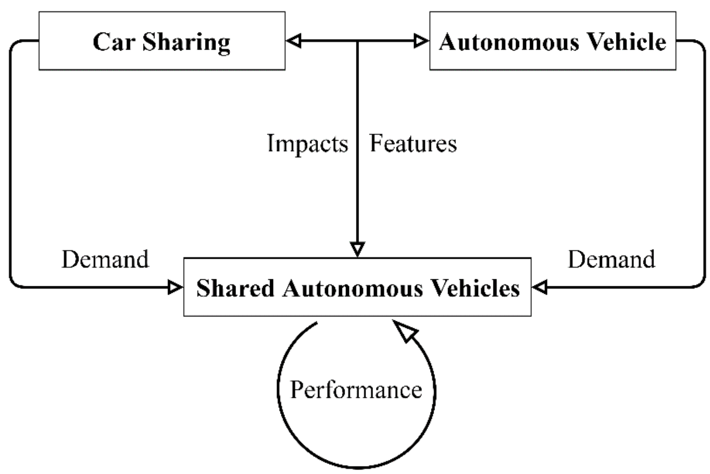



**Figure 2.1 Conceptual diagram of research flow**

In our discussion on the impacts and features of SAVs, we note that SAVs will have benefits in emergency transportation management, flexible traffic planning response, and reduction of greenhouse gas emissions and many levels of transportation modes that have not been included in previous studies. The relationship between SAVs and other transportation modes (including taxi, bike, car sharing, car rental and public transport) is first discussed in this study. In addition, discussion about the negative aspects of car sharing, AVs and SAVs was limited because we would like to focus more on how SAVs benefit from the advanced features of car-sharing and AVs. Furthermore, future research directions on the demand aspect of SAVs were also discussed by systematically reviewing relevant topics that have been included in car-sharing and AV studies that have not been mentioned in the SAVs study. The result shows that: topics related to mode split analysis, before and after studies, users' behaviors, and etc., could be further focused in the SAVs (more in Section 2.1.2). Lastly, modeling among scenarios and different attempts at the operation of SAVs were demonstrated in this study as a guide for the performance study of SAVs in the future. Adding more features, realistic issues and competition strategies could provide more scenarios for SAV simulations. Also, combining a new transportation mode and implementing new operation modes such as dynamic ride sharing, real-time pricing management and private vehicle sharing scenarios were noted in the final section of this paper on the performance study of SAVs.

### 2.1.2 Car Sharing

#### 2.1.2.1 Impacts and Features

Private vehicles have become a necessity of our daily life in terms of the freedom and civilization of the transport industry. It is also noticeable that the increasing number of private transport vehicles has been causing traffic congestion, air pollution and energy consumption for decades. In particular, the greenhouse gas emissions, which are mainly generated from cars and trucks, have a considerable correlation with the level of congestion, in particular in urban areas (Barth and Boriboonsomsin, 2009). Although public and non-motorized transportation could offer alternatives considering the constraints, followed by private vehicles, issues such as flexibility and service range are still considered barriers to the industry.

Researchers have discussed impacts and benefits of the involvement of the car-sharing system, which are presented in Table 2.1. It provides a clear blueprint of the potential capability of this market. Car sharing has been evaluated as an efficient alternative in terms of urban mobility that could be used more efficiently and economically. The main target customers are people who cannot afford to own a private vehicle or the occasional users (Litman, 2000). This service increases the economic productivity of job-searching and employment because it alleviates the deficiency of not possessing a vehicle for individuals or enterprises, which leads to progress in promoting the equity problem caused by disadvantaged transportation. Furthermore, users who are represented by the multimodality model are more likely to become the potential target customers than the group that was labeled as representing the "mono-modality" model (especially mono-modal car users). Accordingly, cycling and public transport would be essential for car-sharing organizations as an efficient supplement when providing mobility services (Nobis, 2006). For this reason, it would be worthwhile to expect the further maturation of the car-sharing market while integrating the whole transport system overall with other mobility alternatives. In recent years, this sharing economy mode has been successfully launched and is spreading over several nations around the world. Extensive works in terms of the appraisal of this rising mode have been conducted, aiming in particular at the subsequent effect corresponding with the condition after its popularization. Martin *et al*. (2010) demonstrated the correlation between the car-sharing market and the household vehicle holdings, in which a comparison study was conducted based on people's attitudes after using the car-sharing system. The study found a reduction in the number of the vehicles from households and roads. The need for fixed ownership costs was also found to be eliminated because of the reduction in vehicle ownership. Thereafter, the VMT was also evaluated as decreasing and the greenhouse gas emissions would then be significantly reduced (Firnkorn and Müller, 2012; Martin and Shaheen, 2011). In addition, the reduction in the static land consumption cost, traffic congestion, accidents and other environmental impacts shall be foreseen from the boost of shared economy.

**Table 2.1 Studies on the impact of the car sharing**

| Source | Inference |
|---|---|
| Litman (2000) | More efficient usage of vehicles in terms of the urban mobility |
| Nobis (2006) | Traffic solutions by combining with cycling and public transport |
| Martin *et al*. (2010) | Reduction in household vehicle ownership |
| Martin and Shaheen (2011) | Fewer vehicle-kilometers traveled and greenhouse gas emissions |
| Firnkorn and Müller (2012) | Less static land consumption |

#### 2.1.2.2 Implications for SAVs

With further development of the car-sharing system, numerous studies have focused on model simulation works to contribute to the refinement of the whole system, in particular for operation or management. Also, the complaints and dissatisfaction from the users increased as the demand increased soon afterward. The issue caused by the vehicle imbalance through relocation of operations seems to be the essential element in terms of putting forward a solid, efficient and satisfactory service as a whole. In this case, autonomous technology can help with relocating vehicles in the shared fleet by applying more flexible and smooth dispatching management. Different scenarios were proposed for moving the vehicles around the stations based on customers' needs (Wang *et al*., 2010; Barth and Todd, 1999). Operators will not only have to manage the departure, arrival, and relocation to be a very competitive transportation mode, but also need to minimize the stock of vehicles, and the connections with limited parking spaces, while maintaining an efficient level of service (Kek *et al*., 2006). In addition, labor and logistics costs are also regarded as an essential constituent of the whole system.

At present, the automated technology has emerged as a possible alternative for resolving the obstacles caused by the conventional car-sharing system. The president of ZIPCAR mentioned that people envisioned the world where car sharers outnumber car owners and the AVs will be what turns that vision into a reality. He excitingly demonstrated the conjecture about the scheme that AVs are expected to be on the streets. While encountering the barriers caused by the limitation of the car-sharing system, the adoption of an autonomous technology would reshape the way that people live and travel (Ceille, 2017). The re-equilibrium system derived from the success of automation is regarded as the reason for the great uptake of SAVs over the original car-sharing system. Because of AV technology, drivers would be able to free up their hands, which represents huge technology-led progress. Also, the operators could eliminate the relocation issue caused by limited parking spots, which leads to a distinctive drop in corresponding costs (Bertoncello and Wee, 2015). Scholars then pictured scenarios applying the AV technology to the existing car-sharing mode, in which SAVs inherit the strengths and features from these two.

### 2.1.3 Autonomous Vehicles

#### 2.1.3.1 Impacts and Features

Over the past years, car manufacturers have been working on installing a driving assistant, parking control and even fully autonomous systems to vehicles (Fagnant and Kockelman, 2015). Numerous manufacturers, such as Google, Tesla, BMW, Toyota, Volkswagen, etc., have invested considerably in pilot studies around the world. Striking news came while stakeholders in the industry were working on a vigorous transformation of the mobility of people. Companies such as nuTonomy and Uber took the lead in launching a driverless taxi service to the public in Singapore and Pittsburgh, and it could be confidently predicted that the service will spread to the wider public in the foreseeable future after experiments and evaluations have been finalized. In addition, Tesla's fully autonomous hardware would be available for all models of new Tesla cars by 2018; the announcements from Ford, Toyota and Apple about autonomous technology, all indicate that we are encountering a dramatic change in the development of vehicles and systems (Reese, 2016).

Driverless cars or AVs were addressed in extensive discussions led by scholars, vehicle corporations, governments and even the public, particularly in recent years. People envisioned that AV technology has in essence the potential of transforming the mode of transport. As a result of this technology, reductions in transport-related fatalities, energy consumption, pollution and the cost of traffic congestion were offered by addressing it to the stage of the development of our transport mobility (Anderson *et al*., 2014). In addition, as stated in the previous section of this study, the introduction of AV technology not only offers multiple benefits individually but also provides us inspiration in terms of transforming the mobility into a shared autonomy in the foreseeable future.

Burns (2013) projected that vehicles with fully autonomous technology will provide a drop in the deaths, injuries and property damage caused by traffic crashes. The driverless vehicles in particular would respond to nearby crashes dynamically, in order to evade a latent incident while saving more time from the potential traffic congestion. The smoother traffic flow and lighter vehicles would also reduce emissions and congestion (Burns, 2013). Similarly, Atiyeh (2012) and Shladover *et al*. (2012) all worked on the evaluation in terms of providing optimal traffic flows by minimizing headway, acceleration and braking in the well-organized autonomous system. Simultaneously, as scholars have demonstrated in relevant studies, a system that considers older people and children, and is capacity increasing and well-coordinated will be generated by pushing forward the autonomous technology to reform the mode of transportation (Fagnant and Kockelman, 2015).

#### 2.1.3.2 Implications for SAVs

Fagnant and Kockelman (2015) facilitated an economic analysis in terms of the benefit of AVs by comparing the technology investment based on different market shares. It turns out that only at an added price of USD10,000 does the technology begin to truly become a realistic investment, which provides us with an essential overview of the methods when promoting this technology. Consequently, we should then think of a more efficient mode when applying the autonomous technology to the existing transportation mode. At this point, SAVs, which apply driverless technology to the shared transport mode, offer exciting opportunities for stakeholders involved in the transformation of the mobility of people.

As SAVs come to the front of the field, their possible impacts have been flagged for the public; other, more feasible topics may be found by later impact studies of SAVs. Also, the potential demand and the productivity performance are also essential areas of focus in relevant studies. In the next section, the combination of car sharing and AVs and comparison studies will be discussed, to provide a better outline of their potential and to find the gaps in the demand analyses of SAVs. Following that, a performance analysis will be conducted for simulating and visualizing the ultimate state of the mobility of people.

### 2.1.4 Shared Autonomous Vehicles

#### 2.1.4.1 Impacts and Features

An emerging transportation mode – SAVs, has been addressed to the stage as increasing number of studies on autonomy stimulated the maturity of this sustainable transportation system (Krueger et al. 2016). Ford (2012) demonstrated that SAVs would lead to less energy consumption and environmental impact while providing a much safer, convenient and comfort system than conventional vehicles. On top of that, SAVs preemptively anticipate the future demand and relocate for better adjustment based on supply and demand, which outweighs prospective technology cost in the future (Fagnant et al. 2015). In addition, dynamic ride-sharing (DRS, which serves multiple travelers with one-time trip of AVs) could be further implemented (Fagnant and Kockelman, 2018).

With the maturation of autonomous technology, studies have considered the advantage of both AVs advantages and the SAVs system. The reduction of casualties on the road is one of the most critical advantages provided by AVs. Burns (2013), Fagnant and Kockelman (2015) provided an overview and projection of connected and driverless vehicles that lead to cost savings by eliminating traffic accidents. Moreover, parking areas, such as on-street parking can be reduced with the involvement of AVs (Kek et al. 2006). Consequently, with the improvement of the traffic environment, a smoother traffic flow will lead to decreasing greenhouse gas emissions and congestion in urban areas (Barth and Borboonsomsin, 2009) when vehicle demand stays at a stable level. Given the advantages of AVs, further investigations concerning SAVs were developed under different transportation scenarios, such as shared autonomous taxi systems. Ford (2012) and Kornhauser (2013) stated that profits could be obtained by providing a safer, fuel-efficient, and congestion-alleviated transportation mode under the condition of adopting autonomous taxis.

The development in mobility moves from the shared economy and owned autonomy to the ultimate scheme—shared autonomy, SAVs. Through the studies on SAVs we are able to have a glance at the features and impacts of SAVs while combining the status of car sharing and AVs. In Table 2.2, we summarized the potential benefits and impacts of SAVs based on the combination of studies for a clear idea of the interaction between car sharing and AVs in terms of the transformation of the mobility of people.

**Table 2.2 Benefits of SAVs from reviewed studies**

| Car Sharing | AVs | SAVs |
|---|---|---|
| Low fixed cost on vehicle | Free up the labor cost | Affordable driverless taxi |
| Less land consumption | Driverless technology | Better sharing service |
| Supplement of transit | Congestion reduction | Optimal transportation environment |
| Reduce car ownership | Well-organized traffic flow | Efficient traffic system; reduced VMT |
| Sharing transport mode | Older people/child friendly | Expanded capability of the service |

Ford (2012) visualized the scenario of implementing shared autonomous taxis into automobile-dominant transportation. The study commented that the reduction in both energy consumption and environmental impact comes with the promotion of SAVs while this new mode provides a much safer and more convenient ride, with comfort superior even to that of the private automobile. As shown in Table 2.2, the lower fixed cost led by the sharing mode and the cost saving on labor derived from the involvement of the autonomous technology stimulates the emerging transport mode, such as driverless taxis in this study. Kornhauser (2013) examined the feasibility of assembling the autonomous taxis in a practical region—the state of New Jersey—which indicated the significant rideshare potential in New Jersey along with the reduction in VMT. Burns (2013) scaled different types of vehicles and envisioned the future steps of SAVs in terms of the technology, safety, system design, etc. The smaller land consumption and the more efficient integrity, which combining car sharing and autonomous technology, present us with a smooth sharing service in the future. Furthermore, the emerging features of SAVs would also provide an expanded service outside the original car-sharing system when the autonomous technology is applied, implying that a system suitable for older people and children, and a transit-friendly ecosystem could be implemented throughout this mode.

SAVs have the advantage over the conventional shared vehicles that future demand can be predicted and the vehicles can be relocated in advance, to balance supply and demand. Even though SAVs cost more to acquire and rent than the conventional shared vehicles, the relocation benefits might eventually outweigh the costs (Fagnant *et al*., 2015). Comparing the SAV framework to regular taxis, Burns *et al*. (2013) estimated that SAVs can be more affordable, mainly because of the elimination of the labor cost of taxi drivers. Fagnant and Kockelman (2014) presented a similar indication as the result of an investment simulation based on a higher vehicle cost scenario. Fagnant *et al*. (2015) subsequently demonstrated that an optimal transportation environment would be established by taking all the components into consideration in terms of approaching an overall maximum on the profit.

While reviewing features of SAVs over the existing car-sharing mode and the proposed AVs, the potential could be pictured. Further benefits of SAVs could be imagined by looking at features of car sharing and AVs together. We listed some of the prospective benefits and features of SAVs in Table 2.3. SAVs will have a benefit for traffic management, particularly when facing emergency issues, considering the more efficient sharing mobility and dynamic response to traffic accidents. As such, SAVs could provide a quick response aimed at new traffic conditions by rebalancing the whole system automatically and more efficiently. Moreover, SAVs could adapt to a more flexible traffic plan from a transport management center because of smaller land consumption and optimized traffic flow. In addition, different transportation modes such as bicycles or buses could be part of the trip of SAVs, for which all levels of transport modes could be promoted with the improvement of traffic congestion and other related conditions. Lastly, SAVs would reduce car ownership while optimizing the driving mode of vehicles. Therefore, greenhouse gas emissions can be further reduced with the involvement of this emerging transport mode.

**Table 2.3 Further benefits of SAVs considering car sharing and AVs**

| Car Sharing | AVs | SAVs |
|---|---|---|
| Efficient sharing mobility | Dynamic response to accidents | Traffic management for emergencies |
| Less land consumption | Optimal traffic flow | Flexible traffic planning response |
| Combine new transport mode | Congestion reduction | Benefit all levels of transport modes |

Kirby *et al*. (1974) illustrated the relationship between the roles of transport choices based on the parameters of distance of the trip and the flexibility of these alternatives. One transportation method may dominate to some degree because of overlaps of the benefits in terms of the interactions between the distance, time and destinations (Figure 2.2). When placing the SAVs into the system of the mobility (the white transparent area), features need to be evaluated based on the designated measurement through the two axes. The taxi–SAV overlap shows that SAVs would replace a certain number of taxis within a certain service distance, because of the relatively lower rate led by the sharing economy and cost-saving by freeing up labor. However, the taxi still has more flexibility in shorter service areas, especially in an urban area (such as hailing a yellow cab in Manhattan, New York, rather than applying for an SAV on the cell phone). The overlap of SAVs and car sharing indicates that SAVs could replace some proportion of shared cars as people would have more flexibility and advantages especially in the shorter service areas (such as no need to find parking, lower travel cost, and flexible boarding location in the urban area). However, car sharing would have strengths on longer-distance trips in terms of privacy and guaranteed pick-up time in rural areas where fewer SAVs are generated. SAVs may also have effects on public transport in terms of providing more flexibility. Also, people would regard SAVs as a supplementary alternative of public transport (Yap, 2016), which illustrates the small overlap of SAVs and public transport. SAVs would have a certain market share among all the transport modes as we eliminate the cost of installing the automated technology on the vehicles.

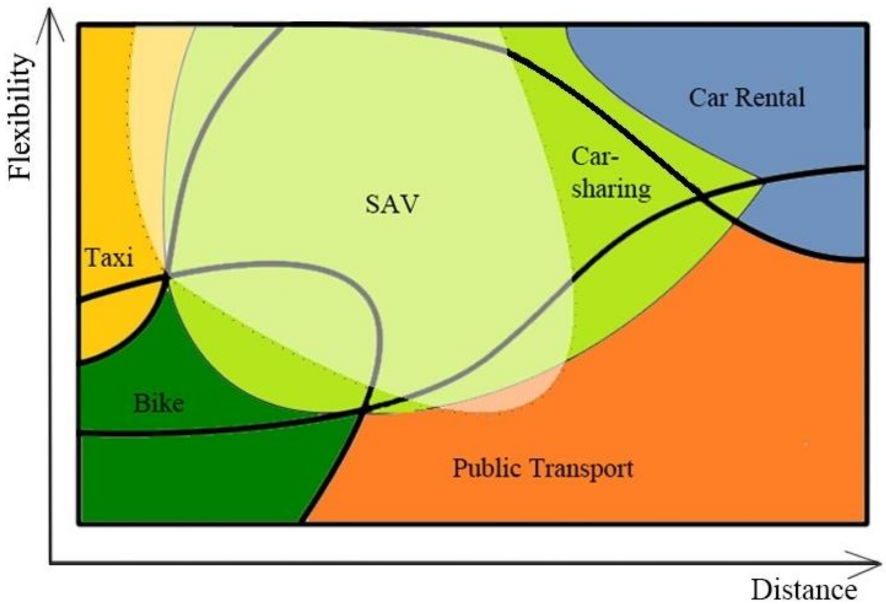



**Figure 2.2 Relationship between SAVs and other transportation alternatives (modified from Kirby et al., 1974)**

### 2.1.5 Demand Analysis

#### 2.1.5.1 Previous Studies

In this section, instead of exploring the performance of system, we focus on users' preferences and demand when using mobility services provided by SAVs. In that case, we looked at the previous studies exploring perspective of both AVs technology and SAVs services.

First of all, attitudes on the benefits, concerns, and implications towards autonomous technology have been discussed. Howard and Dai (2014) investigated the attitudes towards AV perception among 107 prospective adopters in Berkley, California. Safety benefits, no parking hassles, and multitasking while en route were the most attractive items for respondents. However, liability, technology costs when updating to fully AVs, and losing control of cars were the major areas of concern. Furthermore, Kyriakidis et al. (2015) conducted an online survey among 5000 respondents from 109 countries to understand their concerns and attitudes towards different automation levels. In this study, further concerns have been investigated, such as data transmission issues, software hacking/misuse, and willingness to pay (WTP) for automated driving systems. König and Neumayr (2017), meanwhile, delved deeper into the barriers and resistance towards AVs.

Demand analyses of the SAVs have been recently conducted. As it can be concluded from Table 2.4, the factors that were considered in the survey were people's preferences regarding the acceptance of the technology, the operation mode, the willingness to pay (WTP) for different levels of the systems, etc.

Basal *et al*. (2016) conducted a survey among 347 respondents in Austin, USA, assessing people's opinions on different pricing scenarios of SAVs by considering the demographics, built-environment factors and travel characteristics of the respondents. In addition, the study also demonstrated the choice dependence on other people and home-location decisions in AV and SAV conditions for the extended evaluation of the system. In contrast, Yap *et al*. (2016) examined the potential mode when using the concept of SAVs. The stated preference experiment aimed to understand users' attitudes when regarding SAVs as a part of a multimodal train trip. This study provided a unique perspective, thinking about the effective alternative when applying SAVs to a future mode of mobility. Further, the potential customers, passengers' attitudes and the limiting factors have been assessed as a guide for the future promotion of the concept and the technology. Later, to target potential customers, Krueger *et al*. (2016) tried to identify the characteristics of the users and elicit the WTP for service attributes by thinking over different clusters of respondents applying with/without the dynamic ride-sharing (DRS) mode to the discussion. Also, it could be projected that the adoption rate varies across cohorts, which provided the industry with a better understanding of SAVs in terms of the management and operation for a larger market share in the future.

**Table 2.4 Demand studies of car sharing, AVs and SAVs**

| **Car sharing** | **Author/s** | **Inference** |
|---|---|---|
| Potential users survey | Cervero, 2003 | Frequent public transit rider and medium-to-high-density area housing |
| Modal split | Catalano *et al*., 2008 | Car sharing increase up to 10% |
| Before and after study | Stillwater *et al*., 2008 | Examine the built environment and demographic factors for urban areas |
| Stated-preference survey in the university community | Zheng *et al*., 2009 | People's attitudes have a great impact on the acceptance of car sharing |
| Users' behavior | Costain *et al*., 2012 | Environmentally aware people |
| Reduction in car ownership | Firnkorn and Müller, 2015 | Car sharing has positive correlation to the ownership transaction |
| **AVs** | **Author/s** | **Inference** |
| Opinions about the technology | Howard and Dai, 2014 | Understanding the factors that play a role in the industry |
| Intentions, personality traits and attitudes of respondents of AVs | Payre *et al*., 2014 | Addressing seven independent variables |
| WTP with different levels of AVs | Schoettle and Sivak, 2014 | Considering the benefits, intentions and WTP for different levels of AVs in terms of people's features |
| Cross-national attitudes | Kyriakidis *et al*., 2015 | Preferences and inferences among countries were discussed |
| People's attitudes about the potential benefits, concerns and implications of the new technology | König and Neumayr, 2016 | Positive: no car/advanced car; older people and disabled service show the highest agreement; Concern: lack of trust |
| Gender and attitudes | Hohenberger *et al*., 2016 | Gender affects the reactions toward AVs |
| WTP for automation | Daziano *et al*., 2016 | Significant share is willing to pay above $10,000 for full AV technology |
| Considering the supply- and demand-side factors | Bansal and Kockelman, 2016 | Adoption rate varies with the price of technology and people's WTP changing |
| SAVS | Author/s | Inference |
| Acceptance and different pricing scenarios of SAVs | Bansal *et al*., 2016 | Effect of other people's choices and home-location decisions are involved |
| SAVs as public transit of multimodal train trips | Yap *et al*., 2016 | User's features and opinions affect the acceptance in this mode |

| | | |
|---|---|---|
| Adoptions among different clusters of respondents | Krueger *et al.*, 2016 | Opinions on with/without DRS (dynamic ride share) among different travel models |

Although there are few studies that research the demand for SAVs, we could still take a glance at the future trend by combing through studies on the demand for car sharing and AVs. When comparing studies on the demand for AVs, car sharing and SAVs, the potential research dimensions and gaps could be discussed because the research on AVs and car sharing could provide valuable and practical inferences for SAV studies.

#### 2.1.5.2 Inferences and gaps

By reviewing the demand studies among previous research on car sharing, AVs, and SAVs as an interactive combination, inferences and gaps could be extracted, followed by a comparison study of the three topics. As such, items for future discussion on SAVs could be found. Table 2.5 shows the interconnection of the emerging explorations among each range. As SAVs represent the ultimate scenarios in terms of the transformation of the mobility of people, the potential of its further studies could be derived from the works on car sharing and AVs. Consequently, SAVs would inherit the features from the two previous phases, which offer us substantial images for the prospective subjects. Accordingly, it could be expected that the overlaps expressed in the table indicate the probable dimensions for the researchers of SAVs.

When looking at the car sharing–SAVs segment, previous researchers contributed to the successive conjectures that accounted for the effect of the system. Cervero (2003) and Costain *et* *al*. (2012) have conducted surveys of the potential users to explore the features of car-sharing customers. It turns out that the prospective users are transit-prone, environmentally aware people who tend to live in medium-to-high-density areas. Consequently, it could be foreseen that possible aspects of evaluating the potential users of SAVs need to be addressed for evaluating the future change of the market share among all transportation modes. In addition, Zheng *et al*. (2009) addressed the new perspective when assessing the potential in a university community, which reminded us that the results may vary among different people in terms of their habits, attitudes toward the transport mode, and demographic features.

On the other hand, projected impacts were also evaluated by several studies. Catalano *et al*. (2008) forecasted the modal split of the urban transport demand in the city by using the random utility model based on the survey data. Correspondingly, Firnkorn and Müller (2015) considered the willingness to reduce private car ownership with the penetration of the car-sharing system. These works offer insights into determining the probable effects after the involvement of SAVs. Furthermore, compared with the car-sharing system, it is predictable that sharing the autonomy would attract a great number of people from other transportation modes especially when AVs come to the public. Specifically, a before-and-after study (Stillwater *et al*., 2008) indicated that the attitude of the respondents may change with the maturity of the SAV system.

The AVs–SAVs segment in Table 2.5 revealed the connections between these two subjects, in particular toward the implication of the technology and users' features. Howard and Dai (2014) illustrated the preference of the technology changing the variables offered by AVs, whereas Payre *et al*. (2014) addressed more factors with regard to the a priori acceptability of the transport mode, which represented the participants' interests well. Furthermore, the correlation between the acceptance of individuals at the national level was discussed when revealing the interaction between people's concerns and the nation's concerns in terms of development and education (Kyriakidis *et al*., 2015). In 2016, Hohenberger *et al*. (2016) went deeper by explaining the effect of gender on the respondents' usage of AVs. As such, for SAV studies in the future, the expansion of the factors, multiple perspectives when selecting the respondents and the scenarios that establish for the SAV under different operation conditions should be focused. Following that, more valuable variables contained in the effect of the respondents' attitudes could be considered, which could remove the potential barriers that restricted the prior assessments.

Other possible aspects that could be taken into consideration in the AVs–SAVs segment include WTP with different levels of automation in terms of people's features (Daziano *et al*., 2016; Schoettle and Sivak, 2014); consideration of the supply- and demand-side factors when viewing the annual drops in technology prices and increments in WTP (Bansal and Kockelman, 2016); and the potential benefits, concerns and implications based on the users' viewpoints (König and Neumayr, 2017). As a convenient and efficient transport alternative, operators should be concerned with people's WTP and their requirements from the SAV system. The expected change in prices, no matter the cost saving on the technology because of the development of the industry or the rising of users' prospective consumption, would all affect the potential SAVs studies.

**Table 2.5 Future directions of SAVs considering car sharing and AVs**

| Car Sharing–SAVS | AVs–SAVs |
| --- | --- |
| | Opinions about the technology |
| Potential users survey | Intentions, personality traits and attitudes |
| Model splits | Cross-national attitudes |
| Before and after study | WTP with different levels of automation |
| Preference in the university community | Consideration of the supply- and demand-side factors |
| Users' behavior | People's attitudes about potential benefits, concerns and implications |
| Reduction of car ownership | Gender and attitudes |

In summary, SAVs would offer similar or even more advantages and capabilities than conventional car sharing when applying the autonomous technology. However, similar limitations should also be investigated when envisioning the predictable prosperity of SAVs. This requires us not only to contribute valuable topics to the discussion on SAV itself but also to combine the aspects from car sharing and AVs.

### 2.1.6 Performance studies

#### 2.1.6.1 SAV simulation studies

For a long time, research on aspects of the technology evaluation has been conducted across the world. The general consensus is that AVs will soon be available, as long as car manufacturers, institutions and governments make efforts on testing and promotion. While the consequences of the implementation of SAVs remain uncertain, studies have been conducted into the prospects of the system, in terms of effects, components and different modes of operation.

For years, groups of researchers have been working on the optimization of the fleet size provided by an SAV system, the potential effects of establishing a different platform and the application of various modules in simulated environments. Table 2.6 presents some remarkable works in the field, which demonstrated the performance of the SAVs. Ford (2012) took the lead by considering an SAV taxi system based on demand at different hours of the day by making use of the existing infrastructure. This basic demonstration of the system offered a glance at the meaningful inferences led by the implementation of this emerging taxi system when installing AVs to it. People could firstly have a sense of impacts from the SAVs, in which an efficient, environmentally friendly and energy saving mode would be presented to the public soon. Afterward, Kornhauser (2013) applied this innovative mode in practice, which revealed its feasibility in congestion and VMT reduction because of the significant potential in ridesharing. Moreover, further attempts have been facilitated from the perspective of models, in order to simulate more detailed and practical scenarios, which would have a constructive correlation to reality (Boesch *et al*., 2016; Levin *et al*., 2016; Brownell and Kornhauser, 2014; Fagnant and Kockelman, 2014). In conjunction with different schemes of models, the results indicated benefits not only on the traffic performance but also on decreasing the volume of vehicular traffic, which could be derived from the replacement of vehicles (including taxis and private vehicles). The efficient integration and an optimum fleet prerequisite could be viewed.

The ideas about improving the methods of operations fitted well with further innovative directions defined by some scholars improved the efficiency of the system. Fagnant *et al*. (2015) declared that one SAV could replace about nine conventional vehicles by the involvement of the relocation function. Also, the leading benefits such as the reduction in required parking spaces and pollution emissions were regarded as realistic achievements. Moreover, as an extension of the car-sharing mode, SAVs would have wider service coverage by including DRS in the integration. The ability that SAVs can both pick up multiple travelers at the same location or match travelers while the SAV is en route to the destination, stimulated the optimal fleet sizing while reducing the overall VMT (Fagnant and Kockelman, 2015). For this purpose, the urban design for incorporation of SAVs was discussed by Segal and Kockelman by evaluating the DRS–SAV station designs in various schemes (e.g. central business district (CBD), airport and commercial areas). In addition, the performance of the vehicle types in SAVs was discussed as well by replacing privately owned vehicles with shared autonomous electric vehicles (SAEVs) in order to take advantage not only of the SAVs mode but also of electric-powered automobiles (Chen *et al*., 2016). The trade-off was also discussed by considering both the range of the SAEVs and the cost of the system including charging infrastructure, vehicle capital and maintenance. It would be not only the SAV system itself, but the follow-up infrastructure planning, innovative transportation approaches and operation patterns that would thoroughly alter the means of our mobility in the future.

**Table 2.6 Previous performance studies of SAVs**

| Author/S | Method | Inference |
|---|---|---|
| *Fleet Size and Effects Based on Different Scenarios* | | |
| Ford, 2012 | Agent-based model | 79.5% of cars will be replaced by driverless taxis |
| Kornhauser, 2013 | Disaggregate transport demand model | Apply driverless technology to a practical system (NJ, US) |
| Fagnant and Kockelman, 2013 | Agent-based and grid-based model | SAV implications when supplying a small share of trips (3.5%) |
| Brownell and Kornhauser, 2014 | Personal Rapid Transit and Smart Para-Transit models | Calculate fleet size and travel cost using both models |
| Boesch *et al*., 2016 | Agent-based model | Efficiency of the SAV system when the demand changes |
| Levin *et al*., 2016 | Event-based model | Consider realistic traffic flow models in the SAV system |
| *Different attempts at examining the SAV system* | | |
| Fagnant *et al*., 2015 | Network-based model | SAV system with relocation |
| Fagnant and Kockelman, 2015 | Agent- and network-based model | SAV system with DRS |
| Segal and Kockelman, 2016 | Urban design | Urban usage for SAVs |
| Chen *et al*., 2016 | Discrete-time agent-based model | Address EVs to the SAV system—an SAEV model |

2.1.6.2 Research inferences

The previous SAV studies on performance have mainly focused on two dimensions: modeling among scenarios and different attempts at operation. Previous works have pointed to the future directions of the SAV system, where the following studies could contribute.

Different models were applied to facilitate the simulations of the SAV system to better approach the reality. Thereafter, the potential impacts of a SAV system could then be discussed while the researchers constructed models for different scenarios based on existing studies. The review of these articles provided us with a trend among SAV studies. Future inferences, such as adding more features to the simulation system, the realistic problem of an interurban network simulation, and competition strategies when involving other transportation alternatives could be noted and mentioned in future discussions.

In addition, when considering the prospective operation mode of SAVs, more transport alternatives could be involved, such as combining electric vehicles, multimodal transit or non-motorized modes, with the existing SAV system; changes in the operation are also acceptable by involving comprehensive methods. The implementation of the DRS, dynamic pricing based on real-time demand, sharing private AVs with others and other possible definitions of the SAV system could be further discussed in future studies. Furthermore, the completion of the SAV system would stimulate continuous changes in terms of infrastructure, emerging travel mode and modal shift from other traffic modes. Researchers should be aware of all these possibilities by assessing the opportunities of the system.

### 2.1.7 Conclusion

The evolution in vehicle technology and transportation mode is headed for a transformation of the mobility of people. SAVs would enjoy the inherited benefit from a car-sharing economy while providing a sustainable, cost-effective and safer alternative according to the features of AVs. In this study, potential impacts and features of SAVs were found, and further demand and performance research aspects of SAVs were stated by using a systematic approach.

In the section on impacts and features of SAVs, we highlighted the remarkable potential of SAVs in terms of emergency transportation management, flexible transportation planning, and benefits to all levels of transportation modes.

Furthermore, we demonstrated prospective directions of demand studies of SAVs. The results show that topics related to mode split analysis, before-and-after studies, users' behaviors and reduction of car ownership could be examined. Also, people's intentions toward SAVs should be further examined, particularly in cross-national and gender-related studies. Moreover, further informative research shall be included, such as the willingness to pay, people's intention on benefits, concerns and implications considering supply- and demand-side factors shall be accomplished in the future.

Lastly, future performance study aspects of SAVs were illustrated in the latter part of this paper. Two general directions, combining a new transportation mode and implementing new operation modes, such as DRS, real-time pricing management and private vehicle sharing scenarios were first addressed in this study.

## 2.2 Methodologies and Tools

In our study, clustering methods were applied when exploring the relationship between SAVs services and characteristics of users. Discrete choice models were addressed to calculate the possible demand and supply within the SAV system. Also, agent-based simulation platform was utilized for analyzing the change of the SAV system behavior. In this section, we are going to explain explicitly about methodologies and tools relevant to the study.

### 2.2.1 Partitioning Clustering Algorithms

Clustering techniques are the fundamental missions in current data mining or data analysis works. And the goal of using clustering technology is to explore the descriptive relationship between features of each clusters and characteristics of people or items in clusters.

Partitioning clustering algorithms were applied in this study. In this section, we would like to discuss more on k-means, k-modes, Partitioning Around Medoids (PAM) and A Clustering Algorithm based on Randomized Search (CLARA). When using partitioning methods, users need to pre-set the number of clusters so that the initial instances will be determined. In this case, the method starts from an initial partitioning and moving the instances from one cluster to others till the global optimization is reached.

***K*-MEANS.** The *K-means* is the simplest and most widely used method to minimize dissimilarity that measured by the Sum of Squared Error (SSE). (MacQueen, 1965). Each cluster will have a point called centroid and it represents the means of objects' coordinates within the cluster. The *k-means* algorithm is operated according to the following steps:

The *k-means* algorithm

- Step 1: Initially name *k* points as the cluster centroids.
- Step 2: All of the objects are assigned to their closest centroid.
- Step 3: Calculate the positions of the centroids according to the clusters generated from Step 2.

- Step 4: Repeat step 2 and 3 to make sure that we have the minimized dissimilarity of each cluster.

It is noticed that k-means only deals with numeric values because of the feature of its cost function. And the time-cost when dealing with large dataset would be high since k-means requires to enumerate all of the objects with in each cluster.

***K*-MODES**. The well-known clustering algorithm *k-means* is widely used in different application domains such as image processing, medical diagnosis, and bioinformatics. However, one major limitation of *k-means* clustering technique is that it is inappropriate for dealing with dataset which contains categorical variables. Therefore, *k-modes* clustering algorithm was introduced as an extension of *k-means* clustering algorithm to deal with categorical data (Huang, 1997, 1998). *K-modes* clustering algorithm removed the numeric data limitation of *k-means* clustering algorithm while still maintaining its efficiency [Sharma and Gaud, 2007].

*K-modes* algorithm applies a simple matching dissimilarity measure and replaces the means of clusters with modes. Let $X$ and $Y$ be two categorical objects that have $m$ different categorical attributes. The dissimilarity measure between $X$ and $Y$ can be defined as:

$$d\left(X,Y\right)=\sum_{j=1}^{m}\delta\left(X_j,Y_j\right) \tag{2-1}$$

where

$$\delta\left(x_j,y_j\right)=\begin{cases}0, & x_j=y_j\\ 1, & x_j\neq y_j\end{cases} \tag{2-2}$$

Here $d$ can be considered as the generalized Hamming distance (Kaufman and Rousseeuw, 1990). The *k-modes* algorithm takes *k-means* paradigm to cluster categorical data. When choosing Eq. (1) as the dissimilarity measure, the cost function can be calculated as:

$$F(W,Z)=\sum_{l=1}^{k}\sum_{i=1}^{n}w_{li}d(Z_l,X_i) \tag{2-3}$$

subject to

$$w_{li}\in\{0,1\},\quad 1\le l\le k,\ 1\le i\le k \tag{2-4}$$

$$\sum_{l=1}^{k}w_{li}=1,\quad 1\le i\le n \tag{2-5}$$

and

$$0<\sum_{i=1}^{n}w_{li}<n,\quad 1\le l\le k \tag{2-6}$$

where $k$ is the given number of clusters. $W=[w_{li}]$ is a $k\times n$ $\{0,1\}$ matrix, $Z=\{Z_1,Z_2,\cdots,Z_k\}$ and $Z_i$ is the $i$ th cluster center. The goal of *k-modes* clustering technique is to find $k$ clusters for all attributes that minimizes the cost function. According to Huang (1998) (Huang, 1997), the process of *k-modes* algorithm is as follows:

The *k-modes* algorithm

- Step 1: For given $k$ initial modes, allocate an object to the cluster whose mode has the smallest dissimilarity.
- Step 2: After all objects have been allocated, the dissimilarity are recalculated. If an object is found such that its nearest mode belongs to another cluster rather than the current one,

reallocate the object to the cluster that has nearest mode and update the modes of both clusters.

- Step 3: Repeat Step 2 until no object has changed or some additional predefined criterion is met.

**PAM.** This algorithm is proposed by Kaufmann and Rousseeuw, 1987, which also attempts to minimize the SSE similar to *k-means*. The difference is that, by applying PAM, the most centric object in the cluster is targeted while the implicit mean of the cluster (it is possible that the mean may not come from objects in the cluster). The *quality of a clustering*, which is measured by the average dissimilarity between every non-centric objects and the medoid of its cluster, is considered as a critical definition in PAM. And then, the calculation of the *swapping cost*, when considering switch the chosen medoid to a possible non-centric object, can be obtained by calculating the *quality of a clustering* of the two options before and after the swap.

PAM shows better results than k-means when noise and extreme values exist in the dataset. However, it does not scale well for large data sets. Following is the steps for PAM:

PAM algorithm

- Step 1: Select *k* representative existing objects arbitrarily.
- Step 2: Calculate the swapping cost for each pair of non-centric object and medoid object, *TC*.
- Step 3: If TC < 0, replace the medoid by the non-centric object. And re-assign all of the other non-centric objects to the new cluster.
- Step 4: Repeat step 2 and 3 to minimize the SSE.

**CLARA.** It randomly draws multiple samples out of the large data set and apply PAM on each sample to find medoids of the sample (Kaufman L. & Rousseeuw P.J., 1990). And the best fitted medoids can be found by comparing the result of all samples. It is known that CLARA deals with larger data sets than PAM. However, the efficiency of the algorithm highly depends on the sample size and the quality of it may not be guaranteed if the samples are biased.

### 2.2.2 Discrete Choice Model

**Multinomial Logit Model (MNLM).** The MNLM is often used in social sciences for years and it has been widely applied in transportation research filed especially when dealing with state preference data. It would be clear for researchers to find out the correlation between features of transportation and their possible effects on people.

In the MNLM, we have the utility of individual $n$ when choosing alternative j defined as:

$$U_{nj} = V_{nj} + \varepsilon_{nj}$$

$$n = 1, \cdots, N; j = 1, \cdots, J, \tag{2-7}$$

where $U_{nj}$ is the utility that the decision maker $n$ obtains from alternative $j$. The representative utility $V_{nj}$ stands for the part of the utility that captured by the researcher. And $\varepsilon_{nj}$ captures elements that affect the utility but cannot be observed in $V_{nj}$.

MNLM also has closed-form expression on the choice probabilities:

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_j e^{V_{nj}}} \tag{2-8}$$

where $P_{ni}$ is the probability that individual $i$ choses the alternative $i$.

The model also follows two restrictive assumptions: 1) $\varepsilon_{nj}$ are i.i.d (*independent and identically distributed*) extreme value. 2) The model has the assumption of IIA (independence of irrelevant alternatives), which represents that the choice of the individual is unaffected by other choices that are available.

**Nested Logit Model (NLM).** It is known that the NLM is an extension of MNLM since it takes interdependence between alternatives that belongs to the same choice set (Hensher, D.A. & Greene, W.H., 2002). In this study, we use NLM to calculate the future demand of SAVs by assuming that people who choose SAVs will have similar characteristics as those who use non-mass transit models.

For any alternative $i$ belong to the nest $N_k$, we have the following choice probability for alternative $i \in N_k$:

$$P_{ni} = \frac{e^{\frac{V_{ni}}{\lambda_k}} (\sum_{j \in N_k} e^{\frac{V_{ni}}{\lambda_k}})^{\lambda_k - 1}}{\sum_{\ell=1}^{K} (\sum_{j \in N_\ell} e^{\frac{V_{nj}}{\lambda_\ell}})^{\lambda_\ell}}$$

$$n = 1, \cdots, N; j = 1, \cdots, J;\ \ell = 1, \cdots, K, \tag{2-9}$$

where $\lambda_k$ represents the degree of independence in unobserved utility among alternatives in nest $k$. In this case, IIA holds with in each nest while it does not generally holds for alternatives from different nests.

### 2.2.3 Agent-based Simulation

The simulation platform we utilized in this study is *artisoc* (version 4.3) developed by KOZO KEIKAKU ENGINEERING Inc. It is a multi-agent simulation platform that give flexibility to users to construct the simulation system according to their own consideration.

A great number of researchers have been conducted their studies in different areas. Kaneda et al., 2010 simulated the pedestrian functions by considering target maintaining, route-choice and etc. Hiwatari et al., 2011 developed the road traffic simulator to analyze the relationship between EV agents and charging station. And Mikami et al., 2016 evaluated the effectiveness of tsunami evacuation and provided valuable suggestions for future evacuation plans.

In this study, we used the platform that provided by *artisoc* to construct the study area according to the network data and our definition for the SAV agents. It is convenient for us that the assumption and the condition of the simulation can be controlled in order to output the results that fits the real situation. In the latter chapters, we will provide more details about our agent-based simulation.

# CHAPTER 3 Data Description

## 3.1 Introduction

First of all, the study area of this study is stated in this chapter. Then, two data sets are included in our study: person trip (PT) data and stated preference (SP) survey data, which will be covered in the following sections. In these sections, we are explaining the survey design and the fundamental information of the data section in order to provide a clear understanding of our study background.

## 3.2 Study Area and Data Source

**Study Area.** Nagoya city is the largest city in central region of Japan and it is also the center of the third-largest metropolitan region. Meito ward of the Nagoya City in Japan is selected as our study area. According to the data base of Meito ward, the information of the area is shown in the following Table 3.1. To be consistence with the SP survey data, we use the number in 2015 here for demonstration.

**Table 3.1 Basic Information of Meito, Naogya**

| Factors | Contents |
|---|---|
| Area (km$^2$) | 19.45 |
| Population by 2015 | 164080 |
| Population Sex Ratio (males per 100 females) | 108.33 |
| Number of Subway Lines | 1 |
| Number of Subway Stations | 4 (1 terminal station: Fujigaoka) |
| Number of Bus Lines | 9 |
| Number of Bus Stations | 94 |

Form the Figure 3.3, the location of the Meito ward can be seen in the red highlighted area. It is noticeable that the land use of this area is mainly residential. The reason why we consider residential land use in our study is that more vacant passenger cars can be provided during the vacant time as SAVs especially during the working hours. Also, terminal subway station is located within the study area so that there could be more potential SAV trips generated for the access/egress trip to the station.

**Data Source.** Accordingly, the PT data set was extracted for Meito area and PT survey was also conducted with in the study area. We used the 5$^{th}$ Chukyo Metropolitan Person Trip Survey as our data source. The mail-based PT survey was conducted from October to November in 2011. The web-based SP survey was conducted by a survey specialist company named Macromill in Japan to guarantee the quality of the data. The operation time of survey is from September 25th to September 30th in the year of 2015.


**Figure 3.3 Meito area in Nagoya, Japan**

## 3.3 Person Trip Data

In this section, we demonstrate the factors that considered in PT data. In addition, more detailed data description will be done in the following chapters according to the different perspective of research direction of this study.

The features that considered in the PT survey can be found in the following Table 3.2 and the expansion factor for calculating the number of the whole Meito ward was used. Origin and destination was also required to answer at the small zone level to locate the accurate trip information.

**Table 3.2 Factors in the Person Trip Survey**

| Factors | Contents |
|---|---|
| Personal and Family Data | Gender, Age, Number of Household, Residential Code |
| Passenger Vehicle Usage | Numbers of Vehicles, Driver's License |
| Person Trip | Numbers of Trips, Transportation Mode, Departing Time, Travel Time, Destination |
| Others | Expansion Factor and etc. |

## 3.4 Stated Preference Survey Data

In this section, we demonstrate the factors that considered in SP data. Similar to the last section, more detailed data description will be displayed in the latter chapters for more detailed discussion.

The outlook of the questionnaire can be found in the Appendix C, and the following Table 3.3 summarized factors that considered in the SP survey. In this SP survey, we asked respondents from Meito ward mainly about their opinions, concerns and preferences related to SAVs. Through the analysis of this survey, we are expecting to provide inferences on future imagination of SAVs development based on the Nagoya, Japan.

**Table 3.3 Factors in the Stated Preference Survey**

| Factors | Contents |
|---|---|
| Personal and Family Data | Gender, Age, Number of Household, Job, Number of Kids |
| Passenger Vehicle Usage | Numbers of Vehicles, Driver's License, Frequency of Driving, Vehicle Vacant Time |
| Person Trip | Trip travel time, Purpose of Trip |
| Preferences on Using SAVs | Interest of SAVs, Interest of SAVs Services, WTP of SAVs Services |
| Preference on Sharing Private Vehicles as SAVs | Expected Income of Providing SAVs, Willingness to Earn of Each SAVs Services |

# CHAPTER 4 Public Preferences and Willingness to Pay for Shared Autonomous Vehicles Services

## 4.1 Introduction

Previous studies have been conducted to discuss the future possibilities of SAVs. Researchers (Ford, 2012; Kornhauser, 2013) discussed about the feasibility of shared autonomous taxi systems and further evaluate the capability of the services when replacing conventional vehicles in the system. In addition, Krueger et al. (2016) conducted the survey among 435 respondents in major metropolitan areas of Australia. This study helps with understanding not only preferences on SAVs, but also willingness to pay of SAVs with/without dynamic ride share. Similarly, Bansal et al. (2016) provided a clear picture of people's preference and concern when providing different pricing scenario of SAVs.

This chapter stands on a different perspective than previous studies. Particularly, rather than considering the value of waiting time, in-vehicle time and travel cost mentioned by Krueger et al. (2016), we further try to provide a detailed analysis of additional services of SAVs such as "larger trunk" for the user who need more spaces, "multi-user" for those who want to share ride with friends, "child-tracking" for parents who would like to monitor the condition of their children when using SAV services, etc. We included 11 services in this study for SAVs in order to acquire more possibilities for the business model of SAVs in the future. In this case, the gaps between research of SAVs and future development in the industries could be filled. And we hope to help with guiding the design and investment directions of SAVs services in the near future.

The objective of this chapter was to evaluate the intention and WTP across different clusters of people when using various additional services that can be provided by SAVs other than the functions that have already been provided by present taxi hailing applications (such as pick up/drop off at designated locations by reserving taxis via smartphone applications). In this study, a stated preference (SP) survey was conducted to obtain people's intentions regarding SAV services and WTP for these in future scenarios. In this survey, we described different scenarios for respondents and aided them with the imagination of using SAVs in the future (in this study, we informed respondents to imagine that this service will be ready to use in the year of 2030). For example, the process of reserving SAVs and how long the SAVs will take for picking up were described in detail for improved understanding. Questions such as "how much would you like to pay if the waiting time after making the reservation drops from around five minutes to one minute?" were provided directly after each scenario description. Then, people's selections were collected by indicating the given amount of money they would like to pay for each additional service of the SAV trip. Socioeconomic characteristics were also obtained in the SP survey. Firstly, clustering techniques were applied for cluster analysis regarding people's intentions of SAV services, and *k*-modes and partitioning around medoids (PAM) were the two clustering algorithms used. The results of these two algorithms were compared. As demonstrated in a later section, *k*-modes was selected as the clustering method for this study. Thereafter, a Spearman correlation matrix was established to identify the significant features of individual correlations in each categorized cluster. In the final step, the WTP for each service was calculated for a further comparative study, considering the results from the clustering and correlation analysis.

The research flow of this chapter is organized as follows. Chapter 4.2 presents detailed information regarding the SP survey. In Chapter 4.3, we describe the cluster algorithm applied in this study. Based on the comparison analysis between *k*-modes and PAM, the merits of the selected *k*-modes method are demonstrated. Chapter 4.4 presents the clustering and correlation analysis results, while discussing the distinct features of each cluster. Furthermore, the WTP for services is calculated for respondents in each cluster. Finally, a conclusion is provided.

## 4.2 Survey Design and Materials

### 4.3.1 Survey design

As we demonstrated in Chapter 3.4, a web-based SP survey was conducted in our study area. The respondents were regarded as invalid when respondents fail to answer questions related to SAVs services or the answered number are obviously unreasonable. As a result, 1036 out of 1050 participants were collected as valid sample size. The survey comprised two parts. In the first part, socio-economic characteristics, frequent trip purpose, and the person you trip with were required. The second stage of the survey aimed to collect attitudes of 11 SAVs services. Furthermore, in case of those who may not be familiar with AVs technologies and SAVs services, detailed instructions of SAVs operation and expected results of each SAVs service were explicitly explained at the beginning of each question.

### 4.3.2 Participants

In Table 4.1, sample distribution of socio-economic characteristics, features of frequency trip as well as the general interest on SAVs are reported.

**Table 4.1 Sample distribution of socio-economic characteristics.**

| Variables | Levels | Percentage |
|---|---|---|
| Gender | Male | 47% |
| Age | Young (16 to 34 years old) | 29% |
| | Middle age (35 to 64 years old) | 60% |
| | Elder (over 65 years old) | 11% |
| Job | Employee | 51% |
| | Part-time | 14% |
| | Student | 9% |
| | Homemaker | 21% |
| | Unemployed | 5% |
| Have child | Yes | 14% |
| Trip with | Family member (less than 6 years old) | 13% |
| | Family member (6 to 60 years old) | 41% |
| | Family member (over 60 years old) | 14% |
| | Friends | 8% |
| | Alone | 21% |
| | Others | 3% |
| Car use frequency | High (at least 4 to 5 days per week) | 32% |
| | Medium (1 to 3 days per week) | 29% |
| | Low (less than 1 day per week) | 39% |
| Interest in SAVs [1] | High | 40% |
| | Low | 60% |

[1] 1 to 5 levels of interest in SAVs are provided in the questionnaire. Level 1 to 2 are regarded as “High” and 2 to 5 are regarded as “Low” interest.

### 4.3.3 Intention on SAV services

In the following Table 4.2, respondents’ interest on each SAVs services was collected. Also, respondents were asked how much they are willing to pay for the services (for example: How much money would you like to pay per trip if you want to use the large-trunk service? 10 JPY, 30 JPY, 50 JPY, 80 JPY, 100 JPY, Other___; 1 JPY = 0.009 USD is used here for currency conversion). In addition, we provided the base fare of SAVs as 100 JPY for 15 minutes and 300 JPY for 30 minutes trip. Thus, the answered price can be regarded as relative price compared to the basic price above.

**Table 4.2 SAV services description.**

| Service | Description | % [1] | WTP [2] | |
|---|---|---|---|---|
| | | | M [3] | SD [4] |
| Short waiting time | Passengers wait for less than one minute to be picked up | 83% | 41 | 41 |
| On time | Difference between actual and expected arrival time is less than one minute | 82% | 43 | 42 |
| Larger trunk | Extra space for large luggage | 78% | 46 | 47 |
| Multi-origin | Sharing the same autonomous car with friends or colleagues from different origins to the same destination | 73% | 46 | 49 |
| Easy boarding | Providing a specially designed car for comfortable getting in/out | 72% | 33 | 50 |
| Multi-user | More than one users share one SAV to the same destination | 69% | 44 | 51 |
| Easy loading | Providing special equipment or design to assist with loading luggage | 69% | 33 | 51 |
| Keep car while shopping | Keeping your belongings in the autonomous car while shopping | 64% | 44 | 53 |
| Longer boarding time | Providing longer boarding time for passengers who have difficulty getting in/out (default boarding time is 20 s). | 60% | 29 | 54 |
| Child tracking | Tracking the movement of children (≥12 years old) when they are using AVs | 43% | 50 | 56 |
| Charging | Providing a charging service for electronic devices | 39% | 24 | 54 |

[1] % indicates the percentage of people interested in the specific service. [2] WTP represents the willingness to pay for the service in USD (1 JPY = 0.009 USD is used for conversion). [3] Mean value of WTP is calculated here. [4] Standard deviation of the WTP is calculated here.

## 4.3 Methodology

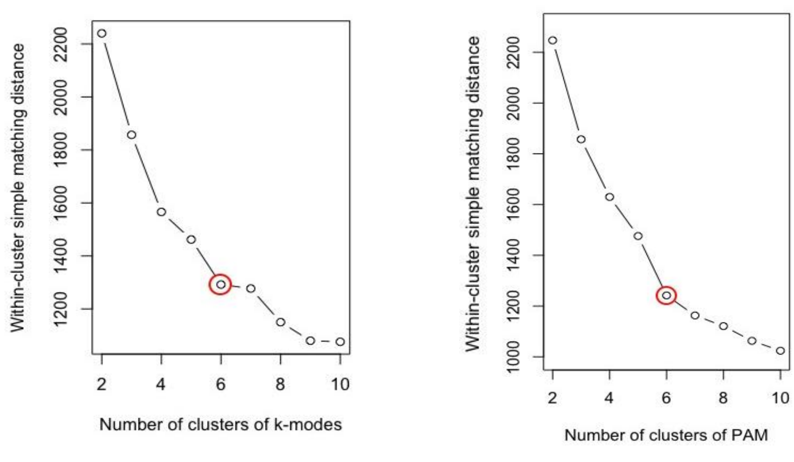
### 4.3.1 Partitioning clustering algorithm

As the primary objective of this study is to explore people's intentions regarding SAV services, the partitioning clustering methods can provide a feasible tool for differentiating the population according to their choices. Partitioning clustering are clustering methods used to classify observations into multiple groups based on their similarity. The most common partitioning clustering methodologies include *k*-means clustering (MacQueen, 1965), *k*-modes (Huang, 1997; Huang, 1998), and PAM and CLARA algorithm (Kaufman and Rousseeuw, 1990).

*K*-means clustering algorithm is the most commonly applied clustering method for partitioning a given data set into pre-specified *k* clusters (Ahmad and Dey, 2007). The observations within the same cluster present high intra-cluster similarity, whereas observations from different clusters are as dissimilar as possible. In *k*-means clustering, each cluster is represented by its center (i.e., the mean of points assigned to the cluster). However, a major limitation of *k*-means is that it is inappropriate for dealing with datasets containing categorical variables. As an extension of *k*-means, the *k*-modes clustering algorithm was introduced to deal with categorical data (Huang, 1997; Huang, 1998). *K*-modes replaces the cluster means with modes, and uses a frequency-based method to update modes in the *k*-means manner, which removes the numerical data limitation of *k*-means while maintaining its efficiency (Sharma and Gaud, 2015).

Another group of extension for *k*-means clustering algorithm (e.g., PAM and CLARA) is to find an actual existing object in each cluster as a representative object and allocate all the objects into the most fitted clusters. Those clustering algorithms are less sensitive to outliers compared to *k*-means, and suitable for categorical variables. PAM begins by determining a representative object for each cluster. This representative, known as a medoid, is the most centrally located point in a cluster. After determining the initial medoids set, the algorithm iteratively replaces one medoid with one non-medoid if this improves the total distance of the resulting clustering (Kumar and Kumar, 2013). However, PAM is more suitable for this study since CLARA only extends PAM to deal with large sample size in order to reduce computing time by applying sampling approach.

Considering the categorical characteristic and small sample size of this dataset, *k*-modes and PAM clustering algorithms are applied in this study. For both *k*-modes and PAM, firstly we need to determine the number of clusters *k*. To estimate the optimal number of clusters, we'll calculate the total within-cluster simple matching distance using different values of clusters *k*. The measure of dissimilarity is weighted by the frequency of features to avoid neglecting rare categories (Kaufman and Rousseeuw, 1990). Generally speaking, the total within-cluster simple matching distance reduces when *k* increases and the degree of descending decreases when *k* gets closer to the optimal number. Therefore, a *kink point* was selected as the appropriate number of clusters to avoid over-distinction (i.e., the observations are clustered into too many groups). Figure 4.1 indicates that $k = 6$ is appropriate for the initial number of clusters for both *k*-modes clustering algorithm and PAM. Interest on SAV services (dummy) are used as variables in clustering algorithms.




(**a**) (**b**)

**Figure 4.1** Within-cluster simple matching distance: (**a**) *k*-modes; (**b**) PAM.

### 4.3.2 Clustering algorithm comparison

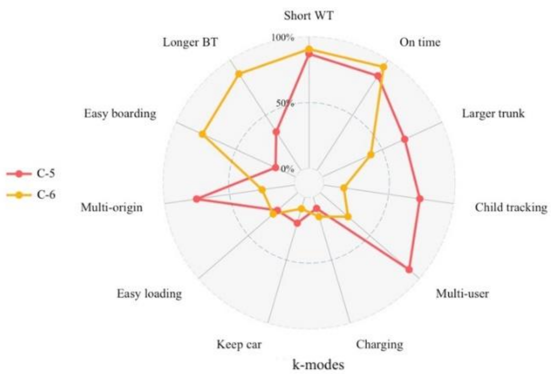
We name the 6 clusters from C-1 to C-6 according to the size of clusters. In order to compare the clustering results of PAM and *k*-modes, we calculated the feature dissimilarities (see notation of Table 4.3 for the definition of dissimilarity) between each corresponding pair of C-1 to C-6 generated from the two different algorithms, indicating similar preferences for SAV services. The results are listed in Table 4.3. In this table, smaller difference indicates less dissimilarity between the corresponding cluster features. Indeed, two clusters show dissimilarity among some characteristics, other four clusters have similar characteristics using two different clustering algorithms. The dissimilarity results demonstrate that the socioeconomic characteristics of four paired clusters (C-1, C-2, C-3 and C-4) according to *k*-modes and PAM are similar, as most dissimilarity values are lower than 5%, and none exceed 9%.

**Table 4.3 Dissimilarity results 1 of four pairs of clusters.**

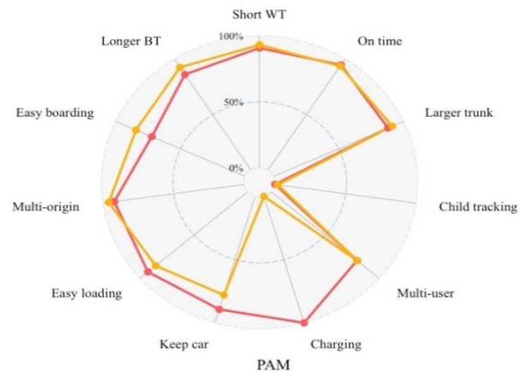
| Variables | Levels | C-1 | C-2 | C-3 | C-4 | C-5 | C-6 |
|---|---|---|---|---|---|---|---|
| Age | Young | 2% | 0% | 1% | 4% | 7% | 16% |
| | Middle age | 2% | 1% | 0% | 6% | 14% | 16% |
| | Elder | 0% | 1% | 1% | 2% | 7% | 0% |
| Job | Employed | 3% | 0% | 1% | 4% | 9% | 12% |
| | Part-time | 1% | 1% | 1% | 3% | 17% | 1% |
| | Student | 0% | 1% | 1% | 1% | 6% | 2% |
| | Homemaker | 3% | 2% | 2% | 9% | 5% | 19% |
| | Unemployed | 0% | 1% | 1% | 1% | 14% | 0% |
| Have child | Yes | 3% | 3% | 1% | 2% | 8% | 19% |
| Trip with | Child | 3% | 0% | 1% | 9% | 1% | 5% |
| | Elder | 1% | 2% | 1% | 1% | 2% | 4% |
| | Alone | 3% | 2% | 1% | 3% | 8% | 10% |
| Car frequency | High | 1% | 6% | 3% | 6% | 1% | 1% |
| | Medium | 2% | 3% | 2% | 3% | 6% | 4% |
| | Low | 0% | 2% | 1% | 0% | 4% | 4% |
| Interest in SAVs | Yes | 5% | 4% | 0% | 7% | 3% | 0% |

[1] The dissimilarity result is the absolute value between the percentages of socioeconomic characteristics of two paired clusters according to *k*-modes and PAM.

However, according to Table 4.3, the two clustering algorithms produce distinguished results for the two remaining clusters (C-5 and C-6). In order to demonstrate the differences further, the percentage of respondents who expressed interest in services from the two remaining cluster pairs are illustrated in Figure 4.2. As indicated in the figure, *k*-modes provides a more distinguishable clustering result compare to PAM. For this dataset, all objects are represented by ordinal variables, which indicate people's preferences for SAV services. It is noticeable that PAM selects *k* objects from the dataset to represent the characteristics of each cluster, while *k*-modes uses mode vectors of categorical attributes to represent cluster centers, where the mode of a value set is the most frequently occurring value (Huang, 2009). Moreover, each object in the dataset consists of 11 attributes (11 SAV services for people to select), so that *k*-modes can provide efficient observation, as the algorithm selects more representative cluster modes than PAM. At this step, the purpose of this research is to seek the representative for each categorized cluster that can effectively explain the characteristics and people's preferences for SAV services, rather than that existing in each cluster. In this regard, *k*-modes is preferable, as we are more concerned with the characteristics of the entire cluster, and the representative selected by the clustering algorithms of each cluster does not necessarily exist in the dataset. Therefore, we select the clustering results of *k*-modes as the clustering algorithm for the following sections.




(**a**)




(**b**)

**Figure 4.2** Interest on Shared Autonomous Vehicles (SAV) services of C-5 and C-6: (**a**) *k*-modes; (**b**) PAM.

## 4.4 Result and Discussion

In this study, *k*-modes clustering and the Spearman correlation matrix were implemented and calculated using R software (version 3.2.1) (R Core Team, 2015).

4.4.1 Clustering results

People from each group can be distinguished in terms of their interests in services that will be provided by SAVs in the future. Table 4.4 presents the major interests in SAV services for each cluster. In total, 36% of respondents who were interested in all SAV services were categorized as cluster 1 (C-1), and 33% were assigned to cluster 2 (C-2), in which most services except for charging and child tracking were accepted. In cluster 3 (C-3), 12% of respondents expressed no interest in any SAV services. Cluster 4 (C-4, 9%) indicated that reliable services (short waiting time, on-time, and larger trunk) were more attractive than others. Moreover, reliable services, multi-user, and child tracking were the highlighted interests in cluster 5 (C-5, 7%). Finally, people in cluster 6 (C-6, 3%) expressed greater interest in the short waiting time, on time, and easy boarding services when using SAVs.

**Table 4.4 Service preferences for clusters**

| Cluster | Size | Interest Services |
|---|---|---|
| C-1 | 36% | Interest in all SAV services |
| C-2 | 33% | Short waiting time; on time; larger trunk; multi-user; keep car while shopping; easy loading; multi-origin; longer boarding time; easy boarding |
| C-3 | 12% | No interest in selecting any SAV services |
| C-4 | 9% | Short waiting time; on time; larger trunk |
| C-5 | 7% | Short waiting time; on time; larger trunk; child tracking; multi-user; multi-origin |
| C-6 | 3% | Short waiting time; on time; longer boarding time; easy boarding |

### 4.4.2 Cluster name definition

Figure 4.3 presents a more straightforward result of the *k*-modes clustering analysis. For the convenience of demonstration, we combine services performing similarly in the clustering results (reliable service—short waiting time and on time; multi-user—multiple user and multi-origin; shopping—keep car while shopping and easy loading; easy boarding—longer boarding time and easy boarding).

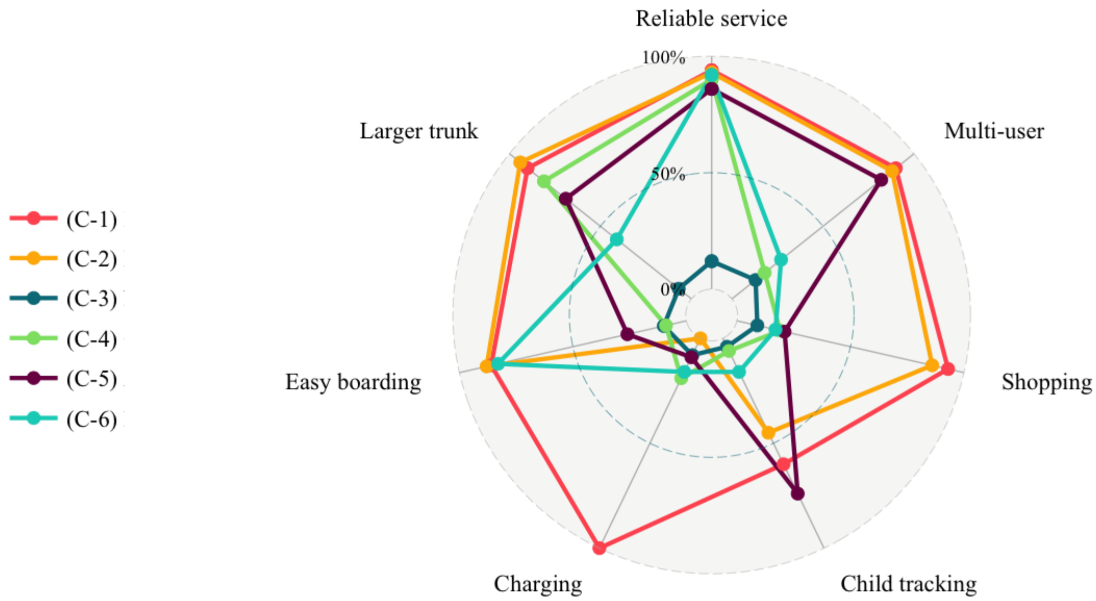



**Figure 4.3** Radar chart of interest services by *k*-modes

In order to have a straightforward impression on each group, we name the clustered groups according to their characteristics of interest services. According to Figure 4.3, "High-interest" is given to C-1 since respondents in this group shows high interest in all groups. "Leisure" is used to define group C-2 since people in this group tends to choose leisure related services. People in this group prefer most of the services except charging and child tracking. C-3 is defined as "Low-interest" for its low interest among all services. C-4 is defined as "Reliable" for that short waiting time, on time and large trunk are preferred by people in this group. Similarly, C-5 and C-6 are named "Reliable & Social" and "Reliable & Boarding" respectively since these clusters show more interest in social and boarding related services. Starting from this section, we will be using the abbreviation to represent the name of 6 groups, which could remind us interested services of each clusters.

Six clustered groups were categorized and a more informative explanation can be obtained by viewing statistical characteristics of each cluster in the next section.

### 4.4.3 Statistical interpretation

The characteristics for each cluster regarding the respondent characteristics in the SP survey dataset are provided in Table 4.5. On this basis, a prior implication could be concluded considering statistical results in terms of the six categorized clusters.

**Table 4.5 Statistical summary of six clusters**

| Variables | Levels | High-interest (C-1) | Leisure (C-2) | Low-interest (C-3) | Reliable (C-4) | Reliable & Social (C-5) | Reliable & Boarding (C-6) |
|---|---|---|---|---|---|---|---|
| Age | Young | 38% | 26% | 18% | 23% | 23% | 19% |
| | Middle age | 52% | 58% | 73% | 68% | 68% | 72% |
| | Elder | 10% | 16% | 9% | 9% | 9% | 9% |
| Job | Employed | 48% | 45% | 63% | 58% | 49% | 72% |
| | Part-time | 17% | 14% | 11% | 13% | 12% | 09% |
| | Student | 12% | 7% | 9% | 9% | 5% | 9% |
| | Homemaker | 19% | 27% | 12% | 13% | 27% | 6% |
| | Unemployed | 4% | 8% | 5% | 7% | 6% | 3% |
| Have child | Yes | 11% | 13% | 18% | 17% | 25% | 19% |
| Trip with | Child | 14% | 17% | 7% | 7% | 9% | 9% |
| | Elder | 12% | 19% | 12% | 11% | 12% | 9% |
| | Alone | 19% | 17% | 27% | 26% | 18% | 44% |
| Car frequency | High | 32% | 31% | 29% | 31% | 40% | 34% |
| | Medium | 26% | 30% | 33% | 30% | 26% | 34% |
| | Low | 8% | 0% | 7% | 7% | 6% | 9% |
| Interest in SAVs | Yes | 45% | 48% | 15% | 25% | 44% | 38% |

The six clusters can be interpreted as follows:

“High-interest (C-1)” group:

- Higher proportion of the younger generation (38%) than other clusters.
- Relatively high interest in SAVs (45%).

“Leisure (C-2)” group:

- Tends to express leisure-used function.
- This group has more elder-people (16%) than the others.
- Fewer single trips (17%) can be observed in this group compared to the remaining clusters.
- Employed occupation proportion (45%) in this cluster is the lowest among all groups.

“Low-interest (C-3)” group:

- Corresponds to the relatively lower interest compare to the other groups.
- This cluster comprises mainly middle-aged people (73%).
- Relatively high proportion of employed people (63%).
- Low interest in SAVs (15%) compared to other groups.

“Reliable (C-4)” group:

- Corresponds to a more conservative way of use since only basic services are preferred.

- People in this cluster express a relatively high interest in SAVs (25%) compared to the "LI (C-3)" group (15%), while the statistical characteristics of the other variables are demonstrated to be similar.

"Reliable & Social (C-5)" group:

- Higher incidence of having children (25%) than other clusters.
- Middle-aged (68%) people dominate this cluster.
- A certain percentage of people exhibit a high interest in SAVs (44%).
- People drive more frequently (40%) in this group than others.

"Reliable & Boarding (C-6)" group:

- Consists of respondents who are generally middle-aged (72%), employed (72%), take trips alone (44%).
- Having some interest in SAVs (38%).

In this section, we preliminarily interpret each cluster by investigating the services of interest and statistical features of the categorized clusters. Thereafter, further discrepancies among groups are demonstrated by observing the correlation between the cluster and people's characteristics in the following section.

### 4.4.4 Correlation analysis

In order to confirm the discussion above, the Spearman's correlation matrix provides a basis for exploring the correlations among assigned clusters and the characteristics within the same clusters. In this manner, further conclusions can be obtained by comparing the Spearman's correlation coefficients of each variable from the clusters. Table 4.6 summarizes the correlation matrix for the categorized clusters and variables. In general, car use frequency was not identified and it has little difference among all groups (as most of the absolute correlation coefficients were smaller than 0.02).

"High-interest (C-1)" cluster:

- Young-generation customers, part-time workers, and students expressed positive correlations by selecting all services.

"Leisure (C-2)" cluster:

- Indicated interest in almost every service, with people in this cluster tending to travel with children or elders, which corresponds to the multi-user and multi-origin services.
- Homemakers and unemployed people showed a positive correlation with selecting shopping-related services.

- Positive coefficient of elders and the negative correlation of having children appeared to affect people's decision of not selecting child tracking and in-vehicle charging services.

"Low-interest (C-3)" cluster:

- Negative significant correlation of interest in SAVs.
- Middle-aged people, particularly employed respondents, were found to be less likely to select any services when considering SAVs.

"Reliable (C-4)" cluster:

- Expressed a similar inclination among all variables, with people in this cluster exhibiting a relatively small correlation coefficient of interest in SAVs
- Basic fundamental services were applied in this context (shorter waiting time, on time, and larger trunk were selected for this cluster).

"Reliable & Social (C-5)" cluster:

- Having children tended to affect people when selecting SAV services.
- Positive influence on high frequent car use and homemakers compared to other clusters, although the correlation was weak at this point.

- Multi-user, multi-origin, and child tracking systems may be reasonable for this group when first attempting SAVs, particularly for households with children.

- Basic fundamental services for families, including shorter waiting time, on time, and larger trunk should also be provided for this group to maintain their daily obligations.

"Reliable & Boarding (C-6)" cluster:

- People who are employees and usually take trips by themselves are more likely to be identified as this group.

- The selected services (shorter waiting time, on time, longer boarding time, and easy boarding) revealed that only functional services will be accepted by this cluster.

- Services that can ensure that the trip is on schedule and improvement of boarding services could eliminate the probability of missing SAVs, particularly for users who are heading to work places.

**Table 4.6 Spearman correlation matrix [1] (multiplied by 100).**

| Variables | Levels | High-interest (C-1) | Leisure (C-2) | Low-interest (C-3) | Reliable (C-4) | Reliable & Social (C-5) | Reliable & Boarding (C-6) |
|---|---|---|---|---|---|---|---|
| Age | Young | 15 | −4 | −9 | −4 | −3 | −4 |
| | Middle age | −11 | −3 | 10 | 5 | 4 | 4 |
| | Elder | −5 | 10 | −3 | −2 | −2 | −1 |
| Job | Employed | −4 | −8 | 9 | 5 | −1 | 8 |
| | Part-time | 6 | −1 | −4 | −1 | −2 | −2 |
| | Student | 8 | −6 | 0 | 0 | −4 | 0 |
| | Homemaker | -2 | 12 | −8 | −6 | 5 | −6 |
| | Unemployed | −6 | 6 | −1 | 2 | 1 | −2 |
| Have child | Yes | −7 | −3 | 4 | 2 | 9 | 2 |
| Trip with | Child | 1 | 9 | −6 | −5 | −3 | −2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Elder | −5 | 10 | −2 | −3 | −2 | −3 |
| | Alone | −3 | −6 | 5 | 4 | −2 | 10 |
| Car frequency | High | −1 | −1 | −2 | 0 | 5 | 1 |
| | Medium | −4 | 2 | 3 | 1 | −2 | 2 |
| | Low | 0 | 3 | −3 | −1 | −2 | 1 |
| Interest in SAVs | Yes | 7 | 11 | −19 | −10 | 2 | −1 |

[1] A correlation coefficient of $p = 0.06$ is statistically significant ($p < 0.05$). The color gradient runs from values indicated by green (lowest) to yellow (median) to red (highest).

### 4.4.5 WTP for services

Based on the survey results, the average WTP can be calculated directly among different clusters of people. Table 4.7 displays a summary of the WTP for different services provided by SAVs. Child tracking, larger trunk, and multi-origin are the services to which people attach great significance when selecting SAVs as their traveling approach. The final column in Table 4.7 indicates that, on average, people are willing to pay more than 50 JPY for using child tracking services, 46 JPY for a large trunk, and 44 JPY for keeping the car while shopping for each trip. Comparative analysis is applied when considering both people's WTP for SAV services and their socioeconomic features, which correspond to the cluster to which they belong. Certain preliminary imaginative scenarios are also provided for specific groups of people with regard to the comparison between the correlation study and the results of the price of services.

People in the "High-interest (C-1)" group are likely to pay more for SAV services than average. The services with the highest average price are child tracking, large trunk, multi-user, and multi-origin. In contrast, people in the "Low-interest (C-3)" group do not have great interest in SAV services, and the average price they are willing to pay is lower than that of other groups for every service in the survey.

People in the “Reliable & Boarding (C-6)” group place a higher value on more useful services and are more willing to pay higher prices for these services. For the on time, short waiting time, and multi-origin services, they can offer 74, 64, and 59 USD, respectively, for one trip, which is significantly higher than the average price. A possible scenario could be that the user hails a SAV online for the commute to work, and an additional amount of money is paid for on time and shorter waiting time services so that they will not be bothered by being late for work. A person may also be willing to pay more money to allow the SAV to wait longer than usual to say goodbye to their children.

However, people in the “Leisure (C-2)” group may not wish to spend too much money on these practical services. For on time and short waiting time service, they only want to pay half the price of that of the “Reliable & Boarding (C-6)” group. Instead, they would like to spend more on most of the other services provided by SAVs. From our scenarios, homemakers or those who do no work may take advantage of SAV services such as multi-user and multi-origin to meet with friends. In the meantime, fundamental features provided by SAVs, including shorter waiting time, on time, and larger trunk may still be considered by the “Leisure (C-2)” group to pursue high-quality trips.

The "Reliable (C-4)" group is more interested in the on time, short waiting time, and large trunk services. Thus, these people are more willing to pay a relatively high price for these services. Furthermore, although only a small number of people show an interest in the child tracking service, they would like to pay the highest price for this service among all those provided by SAVs in the questionnaire.

People in the "Reliable & Social (C-5)" group are willing to pay more money for multi-origin, multi-user, and large trunk services. A possible scenario could be that in which a SAV picks up a student from school, while the parents are free to check the real-time status of their children when the vehicle is en route to meet up with the mother who may be a homemaker and is just about to return home from the supermarket.

Furthermore, we calculate the average added bundle service WTP for each cluster. And generally, "High-interest (C-1)", "Leisure (C-2)" and "Reliable & Boarding (C-6)" groups are more likely to pay over 500 JPY per trip while "Low-interest (C-3)" group would only like to spend less than 222 JPY on these additional SAV services.

**Table 4.7 WTP [1] for different services by groups (USD/trip) [2]**

| | HI-interest (C-1) | Leisure (C-2) | Low-interest (C-3) | Reliable (C-4) | Reliable & Social (C-5) | Reliable & Boarding (C-6) |
|---|---|---|---|---|---|---|
| On time | 42 | 38 | 17 | 43 | 42 | 74 |
| Short waiting time | 43 | 39 | 14 | 42 | 41 | 67 |
| Multi-user | 54 | 56 | 20 | 40 | 50 | 43 |
| Multi-origin | 54 | 56 | 12 | 33 | 53 | 59 |
| Keep car while shopping | 51 | 56 | 24 | 39 | 44 | 49 |
| Easy loading | 44 | 46 | 11 | 32 | 32 | 30 |
| Easy boarding | 43 | 42 | 11 | 31 | 33 | 39 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Charging | 33 | 26 | 14 | 24 | 21 | 27 |
| Child tracking | 64 | 56 | 46 | 54 | 43 | 40 |
| Longer boarding time | 32 | 36 | 8 | 34 | 27 | 36 |
| Larger trunk | 56 | 57 | 18 | 49 | 49 | 44 |
| Bundle [3] | 519 | 504 | 196 | 423 | 437 | 508 |

[1] WTP indicates the willingness to pay for each additional service (1JPY = 0.009 USD). As a reference, local costs such as bus fare: 210 JPY and taxi fare: 650 JPY + 480 JPY/km are provided for comparison of the monetary data in the SP survey. [2] The calculated values are compared to the total average payment for each service. The color gradient values run from green (lower than average) to yellow (similar to average) to red (higher than average). [3] Bundle represents added value of services per trip (not including the base cost of the ride).

To have a further discussion in the pricing policy when promoting the SAV service, the spearman correlation table is provided in the following Table 4.8 to demonstration the internal relationship between services. When looking at the service pairs that have relatively higher coefficient (higher than 0.5), people who prefer "on time" service will have higher possibility of choosing "short waiting time" when using SAVs for saving more time. Similarly, we could found relatively higher correlation among leisure related services, which are highlighted in dark red cells in the lower part of Table 4.8. At this point, we can provide the intuitive inference that the SAV could provide the leisure-oriented bundle service so that people can have more flexibility when shopping, using smart-phones in the vehicle and track their children in real time. More possible business strategies can be provided and it might be interesting to apply further pricing policies to the high correlated services for more profit benefit.

**Table 4.8 Spearman correlation results of services**

| Service | SWT | OT | LT | MO | EB | MU |
|---|---|---|---|---|---|---|
| Short waiting time | 1.00 | | | | | |
| On time | 0.56 | 1.00 | | | | |
| Larger trunk | 0.43 | 0.48 | 1.00 | | | |
| Multi-origin | 0.23 | 0.19 | 0.25 | 1.00 | | |
| Easy boarding | 0.31 | 0.29 | 0.34 | 0.37 | 1.00 | |
| Multi-user | 0.18 | 0.21 | 0.18 | 0.23 | 0.23 | 1.00 |
| Easy loading | 0.33 | 0.32 | 0.39 | 0.3 | 0.44 | 0.37 |
| Keep car while shopping | 0.39 | 0.36 | 0.46 | 0.29 | 0.36 | 0.33 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Longer boarding time | 0.37 | 0.39 | 0.42 | 0.29 | 0.46 | 0.24 |
| Child tracking | 0.31 | 0.31 | 0.35 | 0.27 | 0.37 | 0.22 |
| Charging | 0.39 | 0.4 | 0.43 | 0.3 | 0.37 | 0.23 |

| **Service** | **EL** | **KWS** | **LBT** | **CT** | **CH** |
|---|---|---|---|---|---|
| Easy loading | 1.00 | | | | |
| Keep car while shopping | 0.59 | 1.00 | | | |
| Longer boarding time | 0.56 | 0.55 | 1.00 | | |
| Child tracking | 0.48 | 0.44 | 0.52 | 1.00 | |
| Charging | 0.46 | 0.61 | 0.54 | 0.57 | 1.00 |

## 4.5 Conclusions and Limitations

### 4.5.1 Conclusions

With the development of autonomous technologies, we could expect that the next generation mobility like SAV will provide a cleaner, safer, and cheaper mobility, when all vehicles can drive automatically and driverless mobility can be easily accessed by all of users. This study has taken the lead in investigating the service side of SAVs and understanding user service choices, as well as their WTP for each service.

By comparing the clustering results and algorithm characteristics between PAM and *k*-modes, we apply *k*-modes to our data in order to get more interpretive result. The clustering analysis provided us clear classification according to the respondents' characteristics and their interested services combination of SAV. Six clusters were identified and we defined clusters according to their interested services combination. The defined clusters are "High-interest (C-1)", "Leisure (C-2)", "Low-interest (C-3)", "Reliable (C-4)", "Reliable & Social (C-5)", and "Reliable & Boarding

(C-6)". To obtain more in-depth knowledge of the relationships between respondent features and clusters, a Spearman correlation matrix analysis was applied, and the results provided us with an improved understanding of the manner in which socio-demographic features affect respondent service selections. Inferences of preferences for different services could also be revealed by comparing the calculated WTP for services selected by distinctive clusters.

We compare the result of clustering and features of respondents in each group for further discussion. The young generation with high interest in SAVs, particularly those who have part-time jobs or students, are more likely to be identified as the "High-interest (C-1)" group. It is interesting to note that users in this group are more likely to pay for almost every service during their SAV trips. Older people, traveling with children or other elders, homemakers, and unemployed respondents exhibit a positive correlation with spending more money on "Leisure (C-2)" related services, such as larger trunk, multi-user, and easy loading. For the "Low-interest (C-3)" cluster, middle-aged employed people who express an interest in SAVs are willing to pay less for every service than other clusters. The "Reliable (C-4)" cluster is identified as having a similar tendency of demographic characteristics to the "Low-interest (C-3)" group. However, the coefficient of no interest in SAVs is exhibited less among the "Reliable (C-4)" group than the "Low-interest (C-3)" group. This corresponds to their relatively high expenses for the larger trunk and longer boarding time services. In general, most groups are likely to pay more for the child tracking service even if they do not express great interest therein, which may be attributed to the consensus of protecting the young generation. In the “Reliable & Social (C-5)” group, people with children, those who have high car use frequency, and homemakers express a positive WTP more money for the larger trunk, multi-user, and multi-origin services. Moreover, people who are employed and usually travel alone are more likely to be categorized in the “Reliable & Boarding (C-6)” group, for which significantly greater expenses can be observed for the two functional services (on time and short waiting time). In all, “High-interest (C-1)”, “Leisure (C-2)” and “Reliable & Boarding (C-6)” groups are willing to pay more than 500 JPY/trip on service bundle in addition to the basic ride fare, while the WTP of service bundle of “Low-interest (C-3)” group would be less than 222 JPY/trip.

From the perspective of strategic vision and future business models, the author would like to provide the implication here even though it may seem to be intuitive. The groups of users that tend to pay more according to our result (“HI (C-1)”, “ESRMS (C-2)” and “ER (C-6)”) could be considered as the target users when firstly promoting SAVs services. At the same time, the younger generation who commute to school or part-time job locations, elders who travel with children or friends, and employed users who trip alone for commuting or business trips are the high potential adoption mode when the SAV arrives. On the other hand, it seems that SAVs services will benefit from expanding the opportunities for students who choose schools or part-time jobs, elders who are desired to social while having limitations on their capability to traveling and also could provide convenient and affordable mobility services for solo-commuters so that they could have more opportunities when choosing their job locations. However, we still can’t say that groups with relatively lower WTP indicate less willingness of using SAVs in the future. People who have high demand in using SAVs may just in short of paying high extra expense on SAV services. For instance, students and part-time employed people are more interested in SAVs, yet they may not expect to pay more on SAVs services because of their low income. In this case, it might be interesting to focus on SAV promotion policies regarding different people in terms of the level of income and job types.

At present, on the government side, policy making should be considered prior to the development of the technologies. In this case, this study could provide a guidance for the future needs of SAVs passengers. Also, policy makers could have a clear idea of balancing the profit of both users and SAVs providers. On the other hand, companies from the car manufacturers division (such as Daimler and Toyota) and the service provider division (such as Uber, Lyft, Baidu, and DiDi) are making their effort to bring autonomous mobility to the real world. From the authors’ perspective, it is necessary to balance the profit of mobility services providers and the satisfaction of users prior to the major investigation of the service such as SAV. For this purpose, the results of this study reveal the relationship between SAV services and preference of users and aims to provide a prior view for stakeholders who are planning to develop this next generation mobility service. We also expect that with the help of our study and the following effort of other researchers, next generation mobility which satisfies both the providers and the users will be achieved.

### 4.5.2 Limitations

In this section, we list our limitations and future research directions for other researchers who also would like to devote their effort to next generation mobility services such as SAVs.

Smart survey designs such as pivot style design could be applied to this study by considering the features of respondents, so that a more reliable survey could be conducted. With the limited knowledge of the autonomous technology and SAVs services, we try to explain the scenarios in the survey to make sure respondents could have basic ideas of how SAVs works. In the near future, with the development of people's acceptance of AVs technology, more reliable survey design methods should be considered.

With the fast development of the machine learning algorithms there will be more advanced methods which can be applied to our dataset. In this case, we will keep looking for suitable algorithms to get more accurate results and interpretation in the future.

Even though we provided the interpretation of future SAV scenario for respondents in the questionnaire survey, the limitation of the knowledge of autonomous technologies and SAV would have affected the result of the study. In this study, we didn't consider the price of AVs or the cost of levels of automation. Although, we consider the scenario that people do not need to pay more for owing fully autonomous vehicles, in reality, the price of the technology affects people's preference on SAVs. Also, different pricing scenarios of autonomous technology could be further included in the future research. With the development of the autonomous technologies, we will provide more follow-up studies to respondents to further explain the possible difference of the result caused by the knowledge improvement of respondents.

In addition, in the current scenario, further surveys should be conducted in various locations prior to generalization of the findings, as different expectation types for SAV services could be obtained. Furthermore, more variables will be involved in future work to achieve more substantial results. For instance, scenarios that are more related to operation model could be further considered. Detailed consideration such as people's propensity and willingness to walk to the pick-up point seem to be important to discuss when using this autonomous sharing service.

We asked respondents directly about their WTP for each service, which may underestimate the calculated result. In the scenario of our survey, WTP for the SAV service per trip was applied and it would be interesting to consider the elasticities of the WTP per distance in future studies. Moreover, additional services related to SAVs could be added in future studies, such as the inclusion of periodic inspections and maintenance.

# CHAPTER 5 Analysis on Supply and Demand of Shared Autonomous Vehicles Considering Household Vehicle Ownership and Shared Use

## 5.1 Introduction

As stated already, people's intention of using SAV should be considered in advance before thinking about setting up pilot trails of SAVs. Moreover, it is necessary to discuss the change of market share after the involvement of SAVs. This study focuses on mode choice when SAV are available and the supply of SAV considering the shared use of household private vehicles. The nested logit model of mode choice is developed with person trip data, and the multinomial logit model of autonomous vehicle ownership and shared use is developed with stated preference (SP) data. The demand and supply of SAVs are calculated based on the estimation results of these two models.

The general scenario of this study is to replace all of the privately-owned vehicles to AVs and they can be lent as SAVs so that providers can receive salaries by sharing their AVs. In this case, SAVs are provided by private owners instead of car sharing companies. Owners may keep the SAVs for personal use during the time of day while they can choose the vacant time of their vehicles for sharing. When SAVs are reserved by owners, vehicles cannot be shared to other users, so that the SAV supply decreases. Comparing with the previous study, few of the previous studies have considered preference of SAV providers and included the effect of SAV demand change. Xu et al (2018) demonstrated that the elasticity of demand is not well incorporated in the study of car sharing operation. In this study, we emphasize on the change of the SAV demand by setting different service waiting time (1, 5 and 10 minutes). Two scenarios are established according to the degree of people's acceptance of SAVs in different phases. The relationship between the expected income from SAVs of people and the proportion of SAV supply is further investigated based on the agent-based simulation study, in which the road network and traffic condition could be considered together for an integrated view of this shared autonomy system. In addition, the probability of the waiting time more than 1 minute of SAV trips are calculated to evaluate the behavior of SAVs operation system scenarios in this study.

The research flow of this chapter is shown in Figure 5.1. The data used in this chapter is a large scale person trip survey data in Meito Ward, Nagoya, Japan among six modes (train, bus, car, taxi, two-wheel, and walk), and SP survey data conducted within Meito Ward area on the attitudes towards SAVs. Person trip survey was conducted in 2011 while SP survey in 2015. The mode choice model is developed with the person trip survey data, while the model of AV ownership and shared use intention is developed with the SP survey data. The latter model provides the availability of the private car when the AVs are available at the market as well as the supply of SAVs using household owned private vehicles. The demand of SAVs are calculated by the mode choice model with adding SAVs as a new alternative as well as considering the availability of the private car estimated by the model of AV ownership and shared use. Then, the behavior of SAVs system is investigated by agent-based simulation.

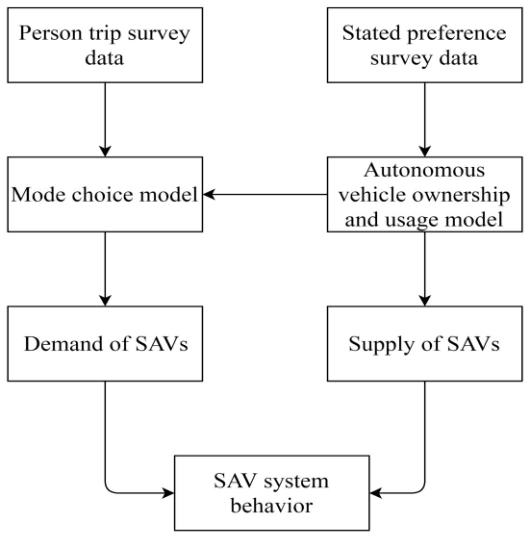



**Figure 5.1 Research flow**

## 5.2 Mode Choice Analysis

A nested logit model was selected for the mode choice analysis with person trip survey data. The structure of the model shown in Figure 5.2 fit our data best and the model estimation result with three nests is shown in the Appendix A for comparison. In this study, mass transit nest and non-mass transit nest were used in order to reflect the classification of the travel mode. The non-mass transit represents a high level of mobility, while rail and bus in mass transit nest cannot offer such kind of flexibility. Travel time, travel cost, waiting time and socioeconomic characteristics were considered in this model. Six alternatives (rail, bus, taxi, car, two-wheel and walk) excluding SAV are used as choice set for the parameter estimate, while seven alternatives including SAV into non-mass transit nest are used for calculating the mode share when SAV is available.

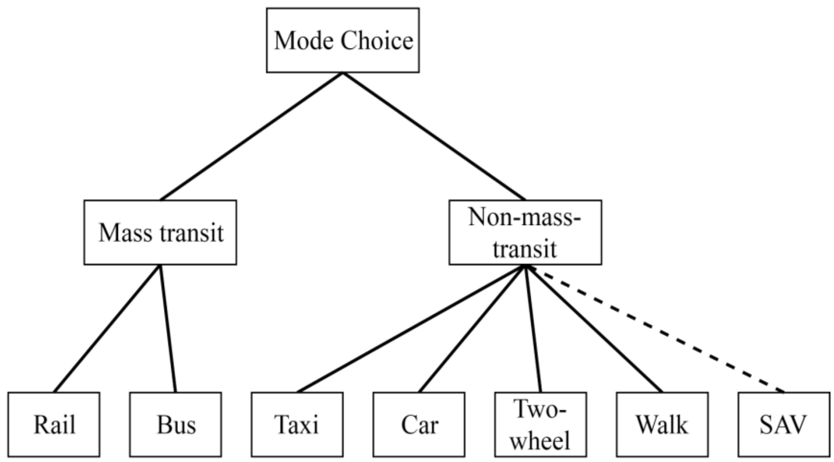



**Figure 5.2 Structure of mode choice model**

In our person trip data, 4542 trips were used for the mode choice analysis. For the attributes of respondents, typical socioeconomic characteristics were considered. We set the age of respondents into three groups for better classification when applying autonomous vehicle ownership and usage model in the following section (young ≤ 15; 16 ≤ middle age people ≤ 64; elder people ≥ 65 years old). In particular, respondents who do not own the private vehicle were regarded to have no availability of choosing the alternative “car”. In addition, the alternative “two-wheel” is set as the combination of motorbike and bicycle, and the availability of choosing two-wheel is judged if the respondent own at least one of these two. The sample distribution of socioeconomic characteristics is shown in Table 5.1.

**Table 5.1 Sample distribution of socioeconomic characteristics of person trip data**

| Variable | Percentage |
|---|---|
| ***Age*** | |
| Young | 28.4% |
| Middle age | 51.7% |
| Elder | 19.9% |
| ***Gender*** | |
| Male | 39.2% |
| Female | 60.8% |
| ***Employment status*** | |
| Student | 29.9% |
| Employed | 22.7% |
| Unemployed | 47.4% |
| ***Trip purpose*** | |
| Commute (Commute to work) | 7.5% |
| Other | 92.5% |
| ***Vehicle availability (not exclusive nor exhaustive)*** | |
| Car | 90.9% |
| Two-wheel (TW) | 76.3% |
| ***Sample size*** | 4542 |

Sample distribution of related variables in the mode choice model for chosen alternative is shown in Table 5.2. In our study, we only consider intra-zone travel within the Meito area for the convenience of the further involvement of SAVs. Travel cost, travel time and waiting time were regarded as critical variables when considering mode choice thus included into the model. To calculate the waiting time of rail and bus, the frequency is used to calculate the headway firstly and half of the headway is regarded as the waiting time of rail and bus. Taxi drivers usually park near the subway station for potential customers. According to zone information such as classification and area size from the PT data, the taxi trip generated from the area with the subway station is assumed to have 5 minutes waiting time. The waiting time of the taxi trips from areas without subway station is set to 15 minutes in this study.

**Table 5.2 Sample distribution of level of service**

| Variable | Rail | Bus | Taxi | Car | TW | Walk |
|---|---|---|---|---|---|---|
| ***Mean*** | | | | | | |
| Travel cost[a] | 2.039 | 2.323 | 5.474 | 0.999 | N/A | N/A |
| Travel time[b] | 0.742 | 0.261 | 0.195 | 0.194 | 0.186 | 0.251 |
| Waiting time[b] | 0.036 | 0.251 | 0.190 | N/A | N/A | N/A |
| Sample size | 120 | 97 | 11 | 1622 | 738 | 1954 |
| ***S.D.*** | | | | | | |
| Travel cost | 0.119 | 0.697 | 0.770 | 0.497 | N/A | N/A |
| Travel time | 0.282 | 0.184 | 0.100 | 0.060 | 0.078 | 0.148 |
| Waiting time | 0.010 | 0.130 | 0.080 | N/A | N/A | N/A |
| ***Sample size*** | 120 | 97 | 11 | 1622 | 738 | 1954 |

[a] The unit of travel cost is 100JPY

[b] The unit of travel time and waiting time is hour

The estimation results of the nested logit model of mode choice with six alternatives was shown in Table 5.3. On the nesting structure, two nests were firstly structured regarding the mass transit classification as mentioned already. According to the preliminary estimation results, the scale parameter for mass transit nest is fixed to one.

**Table 5.3 Mode choice model**

| Variable | Coefficient | t-stat. | Significant |
|---|---:|---:|---:|
| Constant (rail) | -2.199 | -6.433 | *** |
| Constant (bus) | -3.907 | -12.043 | *** |
| Constant (taxi) | -0.710 | -2.016 | * |
| Constant (car) | 0.273 | 3.440 | *** |
| Constant (two-wheel) | -0.099 | -2.821 | ** |
| Travel cost [100JPY] | -0.126 | -3.315 | ** |
| Travel time [hour] | -0.998 | -3.620 | *** |
| Waiting time [hour] | -2.211 | -3.124 | ** |
| Inclusive value (NMT) [b] | 0.2449 | -10.90 | ** |
| ***Rail*** | | | |
| Young | -2.241 | -5.284 | *** |
| Unemployed | -0.605 | -2.446 | * |
| Male | 0.106 | 0.528 | |
| Elder | 0.197 | 0.756 | |
| Purpose (commute) | 1.007 | 4.127 | *** |
| ***Bus*** | | | |
| Unemployed | 0.224 | 0.753 | |
| Male | -0.328 | -1.487 | |
| Elder | 2.419 | 8.792 | *** |
| Purpose (commute) | 1.711 | 4.932 | *** |
| ***Taxi*** | | | |
| Unemployed | -0.163 | -0.835 | |
| Male | 0.253 | 1.373 | |
| Elder | 0.805 | 2.590 | * |
| ***Car*** | | | |
| Young | -0.348 | -2.372 | * |
| Unemployed | -0.129 | -3.067 | ** |
| Male | 0.071 | 2.453 | * |
| Student | -0.350 | -2.440 | * |
| Purpose (commute) | -0.141 | -2.667 | ** |
| ***Two-wheel*** | | | |
| Young | -0.785 | -3.308 | ** |

| Variable | Coefficient | t-stat. | Significant |
|---|---|---|---|
| Unemployed | -0.161 | -3.077 | ** |
| Male | -0.059 | -1.982 | * |
| Student | 0.335 | 2.664 | ** |
| Log-likelihood at zero | -5534.834 | | |
| Log-likelihood at convergence | -4629.408 | | |
| Sample size | 4542 | | |

[a] Walk is the base alternative and significant code is: '***' 0.001 '**'0.01 '*' 0.05 '.' 0.1

[b] Nest (non-mass-transit): taxi, car, two-wheel, walk

[c] H0: the coefficient of the inclusive value equals to 1

As we demonstrated earlier on the nested structure with SAVs in Fig. 5.2, the average mode share on the weekday can be calculated by using the estimated parameters Table 5.3. In order to firstly get the future trend of using SAVs, the probability of choosing SAVs can be obtained by assuming individuals have the same propensity as car on attributes of individuals, given travel cost of SAVs equals to 55 JPY/kilometer (equals to 0.49 USD/Kilometer), waiting time equals to 1, 5 and 10 minutes and travel time set to be the same as conventional vehicles. For comparison, the travel cost of conventional vehicle is 64 JPY/Kilometer (equals to 0.57 USD/Kilometer) (Yamamoto et al. 2016). To calculate the share of the SAV, we assumed to use same parameter value of Car in socioeconomic features. In addition, considering other transport modes within the Non-mass-transit modes, they all share some features with the SAV. For instance, neither Taxi nor SAV use vehicles owned by passenger themselves; both two-wheel and SAV provide flexible trips with fast mobility within the scope of our study. For this consideration, when calculating the constant value of SAV, we used the weighted constant value of taxi, car and two-wheel in the Non-mass-transit nest for the balanced calculation. And factors that affect the utility of SAV can be specified as follow:

$$V_{SAV} = c_{SAV} + \alpha TC_{SAV} + \beta TT_{SAV} + \gamma WT_{SAV} + \delta_p \mathrm{X}_p$$

$$p = 1, \cdots, P \tag{5-1}$$

where $c_{SAV}$ is the constant value of SAV, and it is calculated by the weighted constant value of Taxi, Car and Two-wheel in the Non-mass-transit nest. $TC_{SAV}$ and $WT_{SAV}$ stand for the travel cost and waiting time of the SAV. Travel cost is assumed to be 55 JPY/km and waiting time of the SAV is set to 1, 5 and 10 minutes. $\alpha, \beta, \gamma$ are the estimated parameters in Table 5.3. $\mathrm{X}_p$ represents the socioeconomic factors and the value of estimator $\delta_p$ is assumed to be the same as Car mode in Table 5.3.

As such, market share with the involvement of SAVs based on our assumption could be obtained as shown in the table. Table 5.4 shows 13% (10 minutes) to 24% (1 minute) of the weekday trips are served by SAVs given a particular travel cost and different waiting time (1, 5 and 10 minutes). In the following section, AV ownership and usage model is developed and the market share is recalculated by updating the availability of car.

**Table 5.4 Market share on weekday with/without SAV**

| | Rail | Bus | Taxi | Car | Bike | Walk | SAV |
|---|---|---|---|---|---|---|---|
| Without SAV | 0.027 | 0.022 | 0.003 | 0.348 | 0.166 | 0.434 | --- |
| WT = 1 min | 0.024 | 0.020 | 0.002 | 0.247 | 0.120 | 0.344 | 0.243 |
| WT = 5 min | 0.025 | 0.020 | 0.002 | 0.271 | 0.130 | 0.365 | 0.187 |
| WT = 10 min | 0.026 | 0.021 | 0.002 | 0.294 | 0.140 | 0.386 | 0.131 |

WT: waiting time

In addition, we also conduct the sensitivity analysis regarding different levels of SAV travel cost (see Appendix B). Half, two times and four times of the base cost of SAV (55 JPY/km) is set in the analysis. The Figure B.1 in the Appendix B shows the change of percentage of the market share with different setting of SAV travel cost. From the analysis, when base fare of SAV (55 JPY/km) was given, market share of SAV and conventional vehicles will have similar percentage while the percentage of SAV drops sharply when the cost goes up. At the four times level of the base SAV cost, SAVs can only have around 9.22% of the market share, which is lower than walk (40.05%), car (30.94%) and two-wheel (14.88%). Therefore, to promote SAVs to the users, the base fare (55 JPY/km) provides us the relatively reasonable price setting and the rest part of the study will use the base fare as the travel of the SAV.

## 5.3 Analysis on AV Ownership and Shared Use

The multinomial logit model of autonomous vehicle ownership and shared use is developed in order to forecast the supply of the SAVs using household owned private cars. The SP survey on the adoption of SAVs was carried out at the same area as the person trip survey. The data includes 803 respondents. Sample distribution of explanatory variables used in the AV ownership and shared use model is shown in Table 5.5. In the questionnaire, five levels of interest for SAVs were established and the first two were regarded as “high interest in SAVs” in the estimation. It shows that about 39% of respondents have high interest in SAVs. Around 52% of the people use their car at least once a day.

**Table 5.5 Explanatory variables of AV ownership and shared use model**

| **Variable** | | **Percentage** |
|---|---|---|
| Male | | 48.9% |
| Young generation (< 35 years old) | | 30.6% |
| Employment status: part-time | | 13.3% |
| Car ownership (own car) | | 81.3% |
| Frequent private car use (at least once a day) | | 52.1% |
| High interest in SAVs | | 38.7% |
| **Continuous Variable** | ***Mean*** | ***S.D.*** |
| Log of expected SAV revenue (1000JPY/Month) | 9.381 | 9.381 |
| ***Sample size*** | | 803 |

On the intention for AV ownership and shared use, three options were provided to all individuals for their future choices when all cars on the market are AVs, 1. I will buy AV but not share it (BK); 2. I will buy AV and share it as a SAV (BS); 3. I won’t buy AV but use SAV service (NBS). The sample distribution is shown in Table 5.6. It shows a majority of the respondents will own private AV, will not share it as a SAV and keep it for their exclusive use. However, there will still be around 13% of people would like to buy AV and provide it for SAV, which could be sufficient to operate SAV service at the area.

**Table 5.6 Sample distribution of intention for AV ownership and shared use**

| Intention | Percentage |
|---|---|
| Own private car and do not share as SAVs (BK) | 55% |
| Own private car and share as SAVs (BS) | 13% |
| Don't own car and use SAVs (NBS) | 32% |

The results of the multinomial logit model of intention for AV ownership and shared use are shown in Table 5.7. IIA assumption was tested to consider potential alternative model structures such as nested logit models, which confirmed the appropriateness of the use of multinomial logit model.

**Table 5.7 AV ownership and shared use intention model**

| Variable | Coefficient | t-stat. | Significant [a] |
|---|---|---|---|
| Constant (buy and share) | -1.801 | -3.927 | ** |
| Constant (won't buy but use) [b] | 2.271 | 2.708 | * |
| ***Buy and share*** | | | |
| Male | 0.104 | 0.394 | |
| High interest in SAVs | 1.943 | 7.957 | *** |
| Frequent private car use | -0.206 | -0.793 | |
| Young generation (<34 years old) | 0.323 | 1.143 | |
| Job [part-time] | 0.303 | 0.846 | |
| Own car [private] | -0.658 | -1.862 | . |
| Study | -0.848 | -1.957 | . |
| ***Won't buy but use (share)*** | | | |
| Male | 0.134 | 0.655 | |
| High Interest in SAVs | 1.279 | 7.038 | *** |
| Frequent private car use | -0.566 | -2.789 | * |

| Variable | Coefficient | t-stat. | Significant [a] |
| --- | --- | --- | --- |
| Young generation (<34 years old) | -0.783 | -3.552 | ** |
| Part-time employed | 0.705 | 2.741 | * |
| Own car [private] | -1.763 | -6.828 | *** |
| Log of Expected revenue from SAV | -0.155 | -1.817 | . |
| Unemployed | -0.406 | -1.806 | . |
| Log-likelihood at zero | -770.159 | | |
| Log-likelihood at convergence | -676.57 | | |
| Sample size | 803 | | |

[a] Significant code is: '***' 0.001 '**'0.01 '*' 0.05 '.' 0.1

[b] The "Buy car but keep it" is the base alternative

The estimation results indicate that respondent with a higher interest in SAVs would express their intention for buying AV and then sharing it with other travelers, while current private car owners are more likely to maintain their current status – keep owning vehicles and not sharing them with the public. When looking at the stop to own vehicles and using SAVs as their perspective alternative, high-interest respondents and people who have part-time jobs prefer SAVs while giving up their personal vehicles in the future. On the other hand, frequent car users, young generation and unemployed respondents express less interest in using SAVs service. Moreover, people with lower expected revenue from SAVs are more likely to get rid of their car and turn to the service of SAVs.

## 5.4 Future Scenarios

When considering the future usage of SAVs, the car ownership changes, which corresponds to the three options of AV ownership and shared use estimated in the previous section. Given the change in car ownership, new market share with the involvement of SAVs will be recalculated in this section. For buy and keep group, we came up with two hypotheses regarding the possibility of using SAVs, which will be explained later.

### 5.4.1 Subgrouping of people

We categorized observed individuals in both person trip and SP survey into 16 subgroups in light of demographic characteristics (gender, age and employment status). Based on that, the probability of sharing and utilizing SAVs service could be matched to these subgroups. In addition, vehicle ownership change could be obtained by looking at individual's choice from SP survey in terms of owning vehicles or not. As such, we would categorize respondents in person trip data to the same 16 subgroups and assign probabilities corresponding to subgroups generated from SP data set. In this case, we would be able to acknowledge individual's choice of adopting vehicles in the future when considering SAVs. Thereafter, the supply of SAVs can be calculated from the group of people who choose to buy AV and share it in the future.

### 5.4.2 Mode choice

In respect of the three groups of people (BK, BS and NBS), assumptions of each individual group can be demonstrated as follow: people in BK and BS own vehicles while NBS group stop owning vehicles. Then, we assume that people in BS and NBS group have seven (all) and six (excluding car) alternatives, respectively. Furthermore, for BK group, we set two scenarios as shown in Table 5.8 regarding the probability of using SAVs, which means six (excluding SAVs) and seven (including SAVs) alternatives are taken into consideration respectively for the calculation of new market share. In scenario 1, only limited users have the potential to use SAVs. It indicates that, when SAV firstly come to the public, people who choose to buy private autonomous vehicle but do not want to share it as SAV tend to be more conservative. It is assumed that these people will not use SAVs services over other transport alternatives. In scenario 2, all of the users are assumed to have the probability of using SAVs. SAVs system behavior could be further examined by feeding the supply and demand to the simulation environment with realistic traffic conditions in the following section.

**Table 5.8 Prospective scenarios for people in BK group**

| Scenario | Description |
|---|---|
| Scenario 1 (limited users) | People do not regard SAVs as their potential travel mode since they always have access to private AV |
| Scenario 2 (unlimited users) | People have potential to choose SAVs as well as the other six modes |

By using the results of AV ownership and use model, new market share among all seven travel modes can be recalculated as shown in Table 5.9. The waiting time of SAVs are set to 1, 5 and 10 minutes.

**Table 5.9 Market share considering AV ownership and shared use**

| Waiting time | Rail | Bus | Taxi | Car | Bike | Walk | SAV | Volume [a] |
|---|---|---|---|---|---|---|---|---|
| Without SAV | 0.027 | 0.022 | 0.003 | 0.348 | 0.166 | 0.434 | --- | 0.351 |
| ***Scenario 1: Limited user*** | | | | | | | | |
| WT = 1 min | 0.012 | 0.021 | 0.002 | 0.223 | 0.146 | 0.397 | **0.199** | 0.424 |
| WT = 5 min | 0.012 | 0.022 | 0.002 | 0.232 | 0.156 | 0.418 | **0.157** | 0.391 |
| WT = 10 min | 0.012 | 0.022 | 0.002 | 0.241 | 0.168 | 0.440 | **0.114** | 0.357 |
| ***Scenario 2: Unlimited user*** | | | | | | | | |
| WT = 1 min | 0.012 | 0.021 | 0.002 | 0.186 | 0.132 | 0.370 | **0.277** | 0.465 |
| WT = 5 min | 0.012 | 0.021 | 0.002 | 0.203 | 0.146 | 0.398 | **0.217** | 0.422 |
| WT = 10 min | 0.012 | 0.022 | 0.002 | 0.221 | 0.161 | 0.425 | **0.156** | 0.379 |

[a] Volume represent the percentage of trip volume share brought by car, taxi and SAV.

By observing respondents' choice on car adoption in the future, the probability of choosing SAVs could be further recalculated conditional on distinctive car ownership when SAVs system is launched in the foreseeing expectation. The conservative Scenario 1 (limited user) indicated that user who chooses to buy the vehicle while not sharing it will be unaffected, even under the circumstances that SAVs accommodate more cost savings than conventional vehicles. However, the scenario 2 (unlimited user) that we promoted would specify the consideration that all users would have the chance to choose the service of SAVs as long as it presents superior benefits than other alternatives. Calculation results also show the proportion change of the calculated new market share among all seven alternatives with the respect of two scenarios. The results suggest that approximately 11% to 20 % in the scenario 1, and 16% to 28% of the trips in the scenario 2 will be engaged to SAVs in the foreseeing future based on our assumptions.

In addition, to examine the traffic condition after involving SAVs, in the Table 5.9, volume (traffic volume) is used to reflect the automobile trip share, which consist of car, taxi and SAV trips. The scenario without SAV is used for comparison. From the calculation result of the trip volume share of taxi, car and SAV, the road traffic brought by cars increases to 0.357 – 0.465. Compare to the base trip volume condition that 0.351 share of the trip volume brought by taxi and car, it is foreseen to have relatively more vehicle-related trip and traffic congestion generation because of the involvement of the SAV. In this study, we did not consider the increase of the traffic congestion in the simulation work. With the acceptance of the SAV, it will attract more trip demand because of the advantage in travel cost, mobility flexibility and technology. However, the induced demand of SAV is not considered in this study, future studies considering this issue can be addressed for the more realistic projection of the transportation system with the involvement of SAVs.

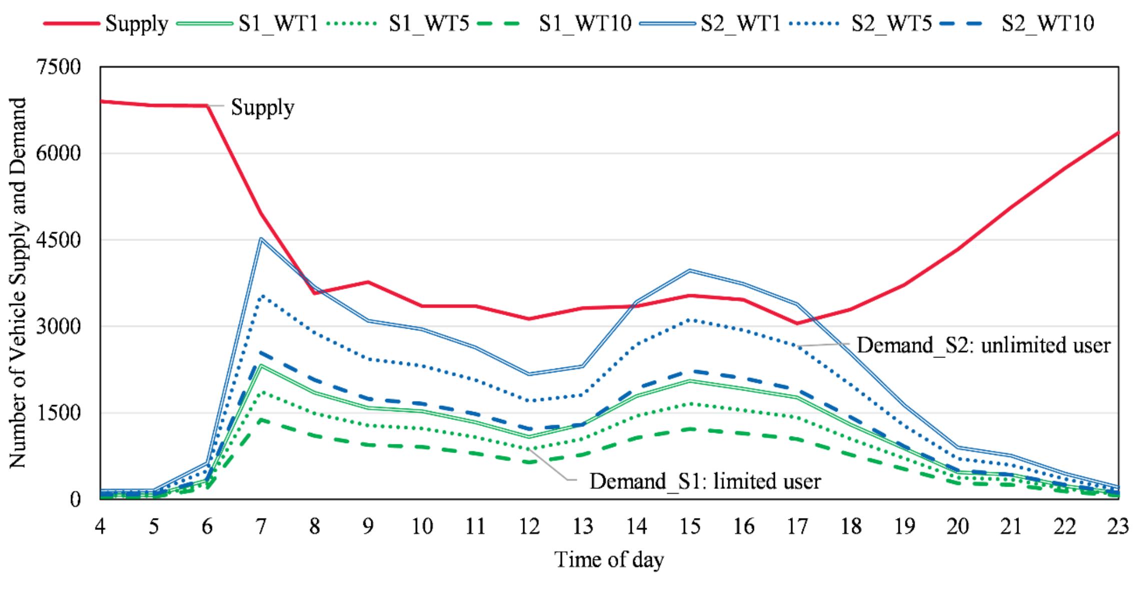
### 5.4.3 Demand and supply of SAVs

The total demand of SAVs based on person trip survey data and the probability generated from SP data can be estimated. Total demand of SAVs will be calculated when considering people who would like to buy the vehicle and would like to share it and those who may not buy vehicle but express positive intention on using SAVs as potential demand of SAVs. Meanwhile, in scenario 2 (unlimited user), a larger potential demand can be involved with the acknowledgment that people may still choose SAVs even though they preferred not to share their personal vehicle as a SAV as long as SAVs express sufficient dominance among other travel modes. Three different sets of waiting time are applied for demand calculation and 1 minute waiting time of SAVs can be considered as measurement of high efficiency of SAV service. The supply of SAVs can be calculated by considering the probability of sharing their purchased vehicles and the expansion factors from the SP survey data as shown in Table 5.10.

**Table 5.10 Demand and supply of SAVs in Meito area**

| Waiting time | Demand (S1: limited user) | Demand (S2: unlimited user) | Supply |
|---|---|---|---|
| 1 min | 22455 trips | 43307 trips | |
| 5 min | 18107 trips | 34005 trips | 9307 vehicles |
| 10 min | 13358 trips | 24359 trips | |

In the SP survey, respondents are also required to answer the available time for their private car within one day. At the same time, the departure time distribution across time of day can be also derived from person trip data. In Figure 5.3, we use the chart with one-hour interval to show demand-supply balance on weekday. The demand of SAVs users will experience the significant incensement during peak hours twice a day. In the meanwhile, the supply of potential SAVs owners would be relatively low during the day time.




[a] WT1, WT5, WT10: waiting time = 1, 5 and 10 minutes.

[b] S1: scenario 1; S2: scenario 2.

**Figure 5.3 Supply and demand of two scenarios**

Therefore, in the foreseeing future, SAVs would have significant benefit for off-peak period users because of the huge amount of the supply in this time of day. It turns out that SAVs could become a supplement travel mode to public transit at un-operated hours such as midnight or early in the morning. Correspondingly, optimized operation system for SAVs need to be established because of the relatively small amount of supply and high demand during the day time, since waiting time seems to be one of the most critical benefits of SAVs when competing with other travel modes including private vehicle, public transit, etc.

## 5.5 SAV System Behavior

### 5.5.1 Simulation specification

An agent-based simulation environment, Artisoc (Kozo Keikaku Engineering Inc.), is applied when combining the demand and supply that we generated from person trip and SP survey data. A snapshot of the simulation is shown in Figure 5.4. The colors of points in the figure represent the different status of passengers and vehicles. The travel speed of SAVs was set to 18.9 and 24 km/h respectively for peak (7 - 9 am and 5 - 7 pm) and off-peak hours (Yamamoto et al. 2016). The distribution of vehicles was assigned according to the population of zones within the study area while trips were generated based on the person trip survey data. For the simplicity of the system simulation, all AVs will return to the home location if no new reservation appears.

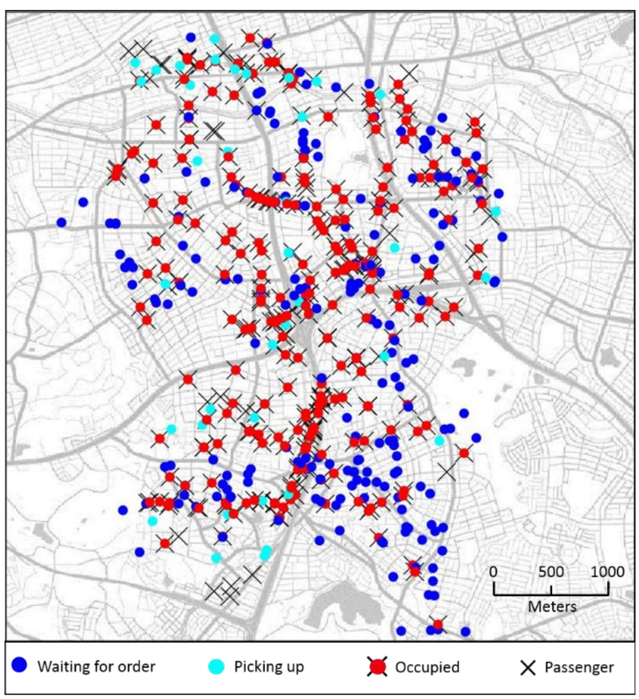



**Figure 5.4 Snapshot of simulation in Nagoya Meito area, Japan**

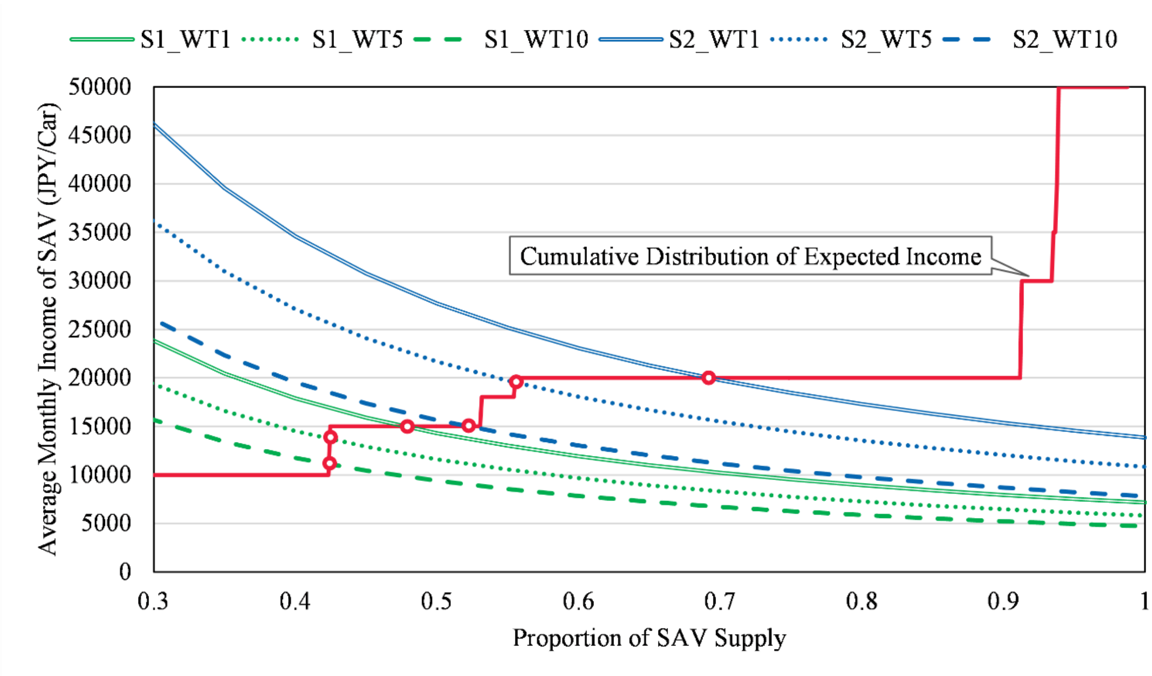
### 5.5.2 Results of the simulation

In the result, average monthly income per SAV was calculated based on the simulation. As shown in the Figure 5.5, we plotted the cumulative distribution of people's expected income from SAV per month (from the stated preference survey) and the simulated monthly income. SAV waiting time is set to 1, 5 and 10 minutes given different proportion of SAV supply. In order to have a better understanding of the relationship between the simulated monthly income of SAV and people's expectation according to the stated preference survey, we assume all of the demand of SAV can be satisfied under any SAV supply level in this study. That is, no trips will be canceled after requesting SAVs regardless the waiting time. In this case, it enables us to obtain that average monthly SAV income increases with the decreasing of the proportion of SAV supply. Consequently, the desired proportion of SAV supply can be obtained from the crossing point when calculated monthly income meets the expected income of SAV providers.

Complicated traffic conditions such as congestion and boarding time when getting on and off the vehicles are not involved in the simulation. The processing time of SAVs such as getting out of the garage was also not considered in this study. Even though, we can still take a glance at the behavior of SAVs system by looking at the relationship between the proportion of SAV supply and income.

Scenario 1 (limited user) can well represent the early stage when introducing SAVs to the public. To meet the monthly expected income of SAV providers, 40 - 50% of the SAVs supply should be put on market. And the average revenue per SAV ranges from 10,000 - 15,000 JPY/Month (90 - 135 USD/Month). As such, at the time when SAV just come to the public, a large amount of the SAVs will remain unused, which would make vehicle owners turn to other options when technology such as vehicle to grid (V2G) comes. Potential inventory of SAVs should be reappraised for the optimism of the integrated system.

In scenario 2 (unlimited user), as more people are getting used to this emerging travel mode, the large percentage of SAVs supply will be used in the system since larger demand trips will be generated at this stage compared to scenario 1. Approximately, 50 - 70% of the SAVs supply can be put on market while the monthly expected income of people will be satisfied. And the average revenue per SAV will raise up to 15,000 - 20,000 JPY/Month (135 - 180 USD/Month).




[a] WT1, WT5, WT10: waiting time = 1, 5 and 10 minutes.

[b] S1: scenario 1; S2: scenario 2.

**Figure 5.5 SAV supply and cumulative monthly income distribution**

In addition, to evaluate the behavior of the SAV system, we also calculate the probability of waiting time over 1 minute after requesting SAVs. We would like to use this probability here to measure the quality of SAV service. Given the same proportion of SAV supply, higher demand will lead to the higher probability of SAV trips with waiting time over 1 minute, which means lower quality of SAV service is obtained. To this purpose, we consider the extreme condition: scenario 2 (unlimited user) with SAV waiting time set to 1 minute, with the highest demand of SAVs among all of the scenarios. All the other scenarios discussed in this study have higher quality of SAV service than the extreme condition.

We plotted the probability of waiting time over 1 minute given 100%, 70% and 40% (the proportion of SAV supply that satisfies the expected income of SAV providers in Figure 5.5) of the SAV supply in Figure 5.6. It can be indicated from the figure that less than 6% of the trips have waiting time more than 1 minute when the proportion of SAV is greater than 40%. In other words, 1 minute of waiting time after requesting SAV is satisfied at over 94% in all of the scenarios. We can conclude that SAVs can provide efficient service for most of the users with waiting time lower than 1 minute according to the simulation result.

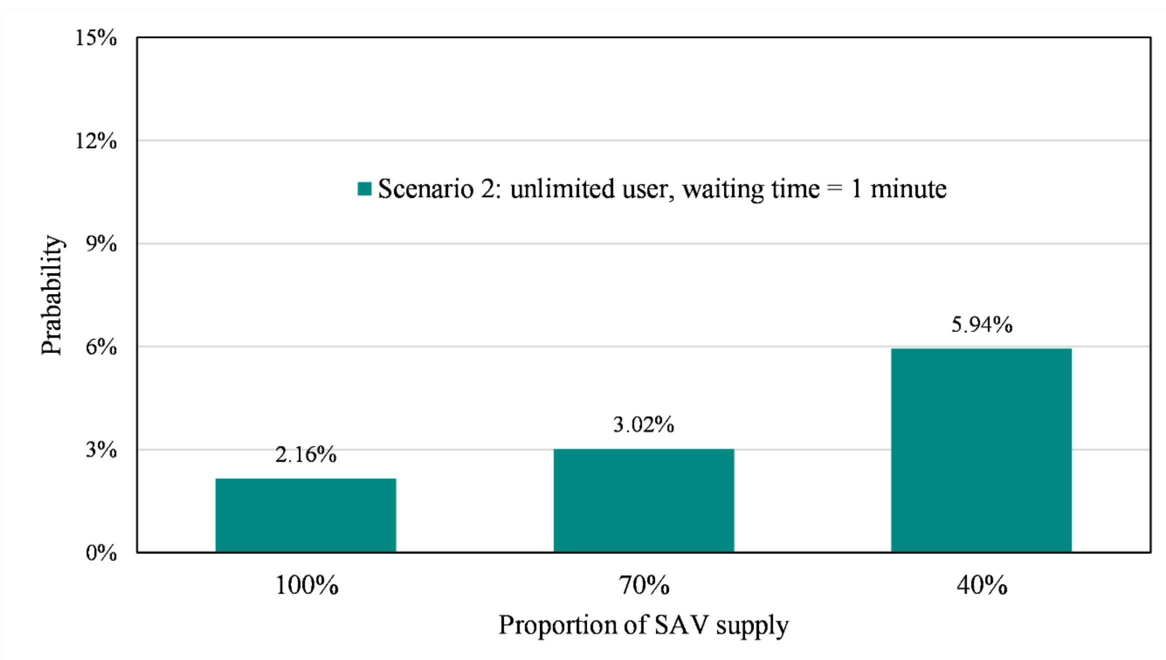



**Figure 5.6. Probability of waiting time over 1 minute**

## 5.6 Conclusions and Limitations

### 5.6.1 Conclusions

This chapter established the mode choice framework considering SAVs as one of the mature travel mode alternatives of residential area in the near future. The assumption follows the idea that autonomous vehicle technology will be well-developed while SAVs offer a cost-saving, flexible and safety options for users of all kinds of trip purpose.

According to discrete choice analyses of SAVs, we noticed that young generation, car owners and frequent car users are less likely to get rid of their car and just use SAVs in the future. Also people who take part-time jobs are more likely to give away their personal vehicle and turn to take advantage of this low expense, relatively high freedom of mobility mode. In addition, SAV operation companies should work more on the income optimization of the system in order to stimulate the supply to the system.

Two scenarios are assumed based on people's acceptance on SAV services, scenario 1 (limited user) indicates that people who buy private vehicles and would not like to lend it as SAVs are assumed not to use SAVs services over other transport alternatives. And all users have the probability of using SAVs in scenario 2 (unlimited user). Three different waiting time are set in order to obtain the demand of SAVs in both scenarios. In scenario 1 (limited user), 11 - 20% of the trips on the weekday can be attracted by SAVs in Meito, Nagoya area of Japan. On the other hand, in scenario 2 (unlimited user) shows that 16 - 28% of the trips will be attracted by SAVs with the increasing acceptance on this emerging transport mode.

In the simulation, SAV vehicle supply and trip demand were calculated from mode choice model and AV ownership and shared use intension model. Based on our calculation, 13358 - 22455 trips will be served by SAVs in scenario 1 (limited user). 24359 - 43307 SAV trips will be generated in scenario 2 (unlimited user). Meanwhile, 9307 personal vehicles will be ready to serve as SAVs in the study area.

We firstly looked at the relationship between simulated monthly income from SAVs given waiting time (1, 5 and 10 minutes) and different proportion of SAV supply in scenario 1 (limited user) and scenario 2 (unlimited user). Then, we plotted the cumulative distribution of people's expected income on SAVs and the simulated monthly income per SAV at different percentage of SAV supply. Based on the result of simulation in scenario 1 (limited user) and scenario 2 (unlimited user), 40 - 70% of the SAV supply can be put on market, meanwhile, the expected income of people will be satisfied at 10,000 - 20,000 JPY/Month (90 - 180 USD/Month).

In addition, probability of waiting time over 1 minute, which represents efficient SAV service level, is emphasized in this study to evaluate the behavior of the SAV system in the study area. At least 94% users can obtain the SAV service with less than 1-minute waiting time. Therefore, according to our simulation, we can state that SAV can provide an efficient service to most of the demand with short waiting time in the study area.

### 5.6.2 Limitations

We listed the limitations in this section for implications on future studies.

1. Because of the limitation of the survey data, we added the SAV choice mode in the non-mass-transit nest for calculation. For more advanced model estimation result, the new stated preference survey considering both SAV and conventional travel modes could be conducted.

2. Congestion did not considered in the simulation study. It is possible that SAV trips will have certain effects on other transport modes on roads. Also, the increasing of the SAVs could bring more traffic, which leads to a relatively congested traffic environment. In the future simulation work, factors that reflect the increasing vehicles and traffic conditions seem to be critical to be included.

3. The induced trips because of the promotion of SAVs were not considered in the study. However, while promoting this emerging transport mode with low-cost, safe and flexible features, more trip demand will be induced. And it is interesting to conduct the future research regarding this issue.

4. Only intra-zone trips were considered. In this study, we didn't consider inter-zone trips, which SAV users travel from/to other districts. In this case, long term trips were not evaluated in this study. However, it might be interesting to evaluate the travel behavior of SAV trips considering short term and long term trips in the further studies.

5. Egress and access trips did not considered in the study. SAVs could be regarded as the mode to deal with the last mile issue. For instance, in our study area, people can take SAVs from their home to subway station for further travel activities. By considering egress and access trips in the future, it is foreseen that SAVs can be applied in wider business scenarios.

6. In this section, even though we considered interest on SAVs in our model, the clustering result in chapter 4 was not applied to the analysis in chapter 5. To tackle this limitation we are currently working on integrated choice and latent variable (ICLV) model considering SAVs services and choices in using SAVs for the potential research direction of our future study.

# CHAPTER 6 Conclusions and Future Work

## 6.1 Summary

With the increasingly development of the autonomous technology, we hold the positive expectation that AVs will finally hit the road in the near future. The desire of the technology and that of the future mobility transformation will be continuously evolved and lead to a society with convenience and sustainability. The pilot of AVs has moved from the designated experiment field to the comprehensive urban environment according to the recent research progress from the automobile industry. One the other hand, the development of the telecommunication such as 5G technology and that of the business development such as ride-sharing and autonomous delivery services are growing with the maturation of the autonomous techniques.

The definition of the first-mover advantage has been considered widely in the domain of emerging business. The early player in the field will have higher possibility to reach larger market penetration and higher profit than other competitors within the industry. Prior to the maturity of the Level 5 autonomous technology, it seems to be critical to evaluate the expected benefit out of the service of SAVs. To maximize the profit of SAV providers and the satisfaction of the users, the modality of the service should be considered. Meanwhile, reasonable wiliness to pay of SAV services at different scenarios in terms of acceptance of the SAV technology, which related to people's knowledge in the technology area.

In our study, we mainly focused on three main parts to picture the future imagination of the society with SAVs. First of all, new features and future implication of SAVs. The comparison study was applied by considering previous studies about car sharing and AV field. We hold the assumption that SAVs will benefit from both the advantage from car sharing and AVs. In Chapter 2, 1) Features and inferences of SAVs in the future, 2) Aspects that need to be considered when working on demand and preference studies of SAVs, 3) Elements that cannot be ignored when research on preference studies of SAVs, are the three main contribution that we concluded in the first main section of our result. Emergency transportation management, flexible transportation planning, and benefits to all levels of transportation modes are the features of SAVs that we summarized throughout the study. In the demand and preference study aspect, topics related to mode split analysis, before-and-after studies, cross-national, gender-related studies, as well as users' behaviors and reduction of car ownership could be examined to get closer to the future scenario when SAVs are provided. Lastly, in the domain of performance and behavior study of SAVs, the two axes: new transportation mode and implementing new operation modes ought to be the good observation for the research conduction, such as considering DRS, real-time pricing management and private vehicle sharing scenarios.

Secondly, in Chapter 4, the author mainly focuses on services that provided by SAVs, and examine the preference and WTP from the users' side. We not only look at the functional service of SAVs such as shorten the pick-up time or arrive on time, but provide more flexibility to the users to let them define the services of SAVs according to their demand and preferences. In the SP survey, 11 services were included. Additional services such as: larger trunk, kids tracking, multi-users and keep car while shopping are the services that considered in our study. Six clusters: "High-interest (C-1)", "Leisure (C-2)", "Low-interest (C-3)", "Reliable (C-4)", "Reliable & Social (C-5)", and "Reliable & Boarding (C-6)", were defined according to the clustering technique *k-modes*. And names of clusters refer to different bundle services that people within each group are interested in. We would like to highlight our thinking here to share with the readers for further consideration and suggestion of the business mode of SAVs services. "High-interest (C-1)", "Leisure (C-2)" and "Reliable & Boarding (C-6)" seem to be the targeted user-groups especially at the early phase, since they are willing to pay money than the people from the other three groups. Furthermore, the benefit of easy-mobility and cost-saving will have positive impact on elders, students, part-time workers and solo-commuters, which SAVs provide more opportunities by improving their access mobility.

Chapter 5 gives a glance at the transpiration market with the involvement of SAVs in terms of market penetration and system behavior. Discrete choice model was applied to calculate the supply and demand of SAVs within the study area and the agent-based simulation was utilized to evaluate the acceptability and efficiency in terms of the operation of SAVs system. Based on the calculation results, with the maturity of the autonomous technology and the increasingly acceptance of SAVs, up to 28% of the trips will be attracted by SAVs from the conventional transportation modes. According to the simulation result, 40 - 70% of the SAV supply can be put on market and the satisfaction of monthly income from SAVs will be balanced. Finally, the services efficiency degree indicates that a reasonable level of services can be provided by SAVs, which 94% users can obtain the SAV service with less than 1-minute waiting time.

## 6.2 Future Work

The collaboration among relevant parties such as automobile industry, infrastructure construction, IT companies and etc. are improved with the development of the technology. Researchers should not only keep the academia field, but also follow the trend of the industry and the demand transformation of the SAV users. For the future work, the author would like to gather more information from multiple aspects and try to provide a comprehensive understanding of the industry with the involvement of SAVs.

In addition to the result of Chapter 4, we would like to stand from the perspective of future enterprises, particularly those who would like to operate SAVs, may provide different vehicle models that are designed to meet various needs. Also, suggestions for policymakers could turn to a more practical discussion regarding the obligation of SAVs once they are implemented on the roads and aim to provide superior services. Furthermore, when examine people’s preferences on

SAVs, in addition to preference on SAV services, we would like to consider travel cost per trip and willingness to pay of services together for the more reliable projection of future scenarios. Also, research on SAV providers and their willingness to earn considering customized service types could be another direction for more solid SAV discussions.

Furthermore, when calculating the market penetration of SAVs in Chapter 5, because of the restriction of our data, some assumptions needed to be set to get the market share of SAVs including travel cost, travel speed and waiting time. We set several waiting times for sensitivity analysis though. At the current stage, we were focusing on the behavior of the SAV system in the future scenario from the operation side, considering changes in SAV demand. Further studies will be focusing on more realistic traffic conditions while optimizing the amount of supply of SAVs in the simulation system. In the mode choice model, access and egress trips to the subway station within the study area for trips going inbound and outbound will be included. Moreover, new operation mode like SAV dynamic ridesharing service can be promoted in order to satisfy the demand of multiple passengers within one-time trip. As such, safety concerns over taxi or Uber drivers will be eliminated and the whole system will become more efficient thanks to the connectivity of AVs fleet. Furthermore, Innovative system operation technologies such as V2G by applying electrical vehicles to the conventional SAVs system can also be discussed as a competitive option considering profit optimization.

There will still be a long way to process until SAVs hit the roads. At that point, a dramatic transformation will lead us to the ultimate stage of our mobility. We need to be prepared for this shift in transportation by the progressive expansion of related studies until that time comes.

# APPENDIX A Mode Choice Model – three nests

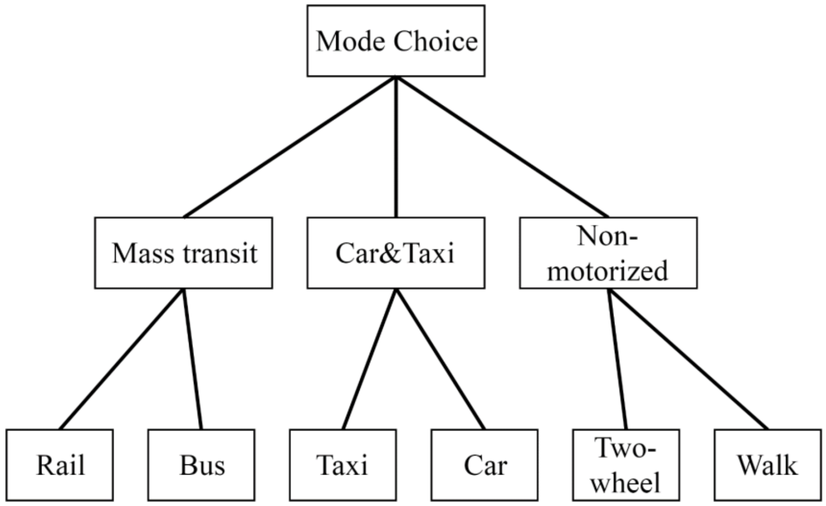



**Figure A.1 Structure of mode choice model – three nests**

**Table A.1 Mode choice model of three nests**

| Variable | Coefficient | t-stat. | Significant |
|---|---:|---:|---:|
| Constant (rail) | -0.044 | -0.172 | |
| Constant (bus) | -3.033 | -9.096 | *** |
| Constant (taxi) | -3.996 | -4.151 | *** |
| Constant (car) | 0.957 | 9.008 | *** |
| Constant (two-wheel) | -0.364 | -4.255 | *** |
| Travel cost [100JPY] | -0.346 | -4.887 | *** |
| Travel time [hour] | -2.845 | -12.208 | *** |
| Waiting time [hour] | -2.190 | -2.364 | * |
| Inclusive value (NMT) [b] | 0.835 | -1.361 | |
| ***Rail*** | | | |
| Young | -3.159 | -7.579 | *** |
| Unemployed | -0.870 | -3.453 | *** |
| Male | 0.197 | 0.955 | |
| Elder | 0.106 | 0.406 | |
| Purpose (commute) | 0.840 | 3.330 | ** |

| Variable | Coefficient | t-stat. | Significant |
|---|---|---|---|
| ***Bus*** | | | |
| Unemployed | 0.305 | 0.930 | |
| Male | -0.269 | -1.195 | |
| Elder | 2.608 | 8.798 | *** |
| Purpose (commute) | 1.999 | 5.623 | *** |
| ***Taxi*** | | | |
| Unemployed | -0.898 | -1.286 | |
| Male | -0.269 | -1.195 | |
| Elder | 3.042 | 3.958 | *** |
| ***Car*** | | | |
| Young | -1.427 | -3.288 | ** |
| Unemployed | -0.453 | -4.857 | *** |
| Male | 0.296 | 3.626 | *** |
| Student | -1.290 | -2.997 | ** |
| Purpose (commute) | -0.572 | -4.120 | *** |
| ***Two-wheel*** | | | |
| Young | -3.198 | -10.089 | *** |
| Unemployed | -0.618 | -5.690 | *** |
| Male | -0.241 | -2.444 | * |
| Student | 1.485 | 4.752 | *** |
| Log-likelihood at zero | -5534.834 | | |
| Log-likelihood at convergence | -4656.588 | | |
| Sample size | 4542 | | |

[a] Walk is the base alternative and significant code is: '***' 0.001 '**'0.01 '*' 0.05 '.' 0.1

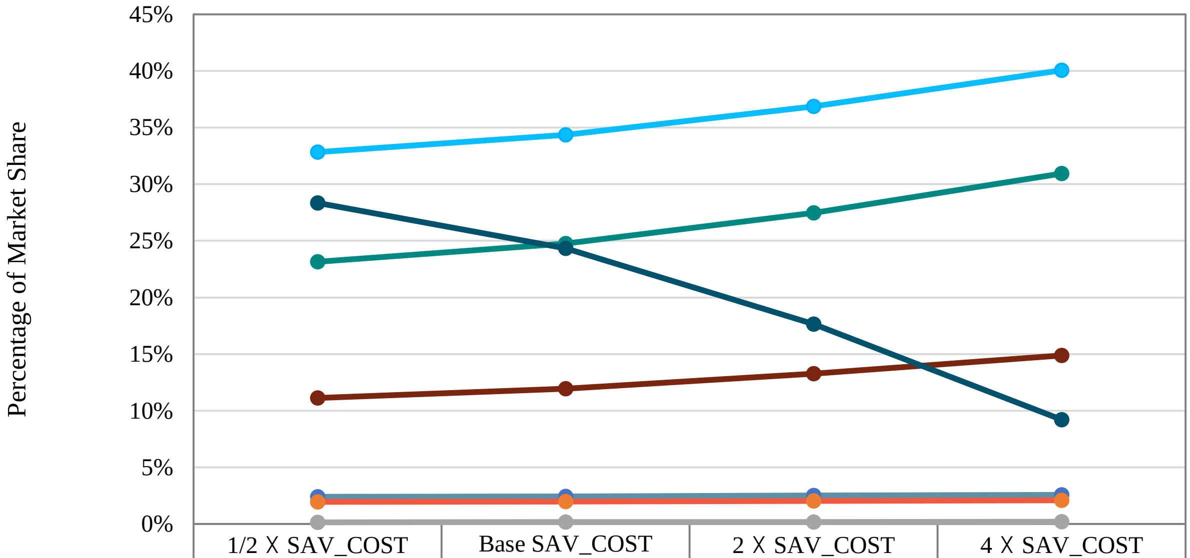
[b] Same inclusive value is set to both "Car & Taxi" and "Non-motorized" nest

[c] inclusive of "Mass-transit" nest equals to 1

[d] H0: the coefficient of the inclusive value equals to 1

# APPENDIX B Sensitivity Analysis on Travel Cost of SAVs

Different price setting of SAVs are set to analyze the change of market share among all transport modes. Half price, double and four times of the base fare (55 JPY/km) of the SAV were used in the analysis.




| | 1/2 X SAV_COST | Base SAV_COST | 2 X SAV_COST | 4 X SAV_COST |
|---|---|---|---|---|
| Rail | 2.40% | 2.44% | 2.51% | 2.59% |
| Bus | 1.97% | 2.00% | 2.05% | 2.11% |
| Taxi | 0.16% | 0.17% | 0.19% | 0.22% |
| Car | 23.15% | 24.75% | 27.47% | 30.94% |
| Two-wheel | 11.14% | 11.94% | 13.27% | 14.88% |
| Walk | 32.84% | 34.35% | 36.87% | 40.05% |
| SAV | 28.34% | 24.34% | 17.64% | 9.22% |

**Figure B.1 Percentage of market share with different levels of SAV cost**

# APPENDIX C State Preference Questionnaire

あなたご自身に関するアンケート

下記アンケートにご協力お願いいたします。

**当アンケートの回答者の皆様へお願い**

マクロミルモニタの皆様にはモニタ規約にて「調査についての守秘義務」の徹底をお願いしています。

当アンケートの内容および当アンケートで知り得た情報については、決して第三者に口外しないよう(掲示板やホームページへの書き込みを含む)、ご協力お願いします。

- ⓘ必須入力

**Q1 あなたのお住まいの地域をお選びください。**
【必須入力】

- 名古屋市 千種区
- 名古屋市 東区
- 名古屋市 北区
- 名古屋市 西区
- 名古屋市 中村区
- 名古屋市 中区
- 名古屋市 昭和区
- 名古屋市 瑞穂区
- 名古屋市 熱田区
- 名古屋市 中川区
- 名古屋市 港区
- 名古屋市 南区
- 名古屋市 守山区
- 名古屋市 緑区
- 名古屋市 名東区
- 名古屋市 天白区
- 名古屋市以外の愛知県の地域
- 上記以外の都道府県

ここで改ページ

- ⓘ必須入力

**Q2 あなたの職業をお選びください。**
【必須入力】

- 公務員
- 経営者・役員
- 会社員(事務系)
- 会社員(技術系)
- 会社員(その他)
- 自営業
- 自由業
- 専業主婦(主夫)
- パート・アルバイト
- 学生
- その他
- 無職

ここで改ページ

- ⓘ必須入力(全項目)
- 排他選択肢: 22. 同居している子供はいない

**Q3 あなたはご自身のお子様と同居していますか。同居しているお子様の性別、年齢をすべてお選びください。**
【必須入力】

| | 0歳 | 1歳 | 2歳 | 3歳 | 4歳 | 5歳 | 6歳 | 7歳 | 8歳 | 9歳 | 10歳 | 11歳 | 12歳 | 13歳 | 14歳 | 15歳 | 16歳 | 17歳 | 18歳 | 19歳 | 20歳以上 | 同居している子供はいない |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 男のお子様 → | | | | | | | | | | | | | | | | | | | | | | |
| 女のお子様 → | | | | | | | | | | | | | | | | | | | | | | |

## 自動車に関するアンケート

Q1 あなたは運転免許を持っていますか。

- ○ 1. 持っている
- ○ 2. 持っていない

Q2 あなたのご自宅や勤務先では、自家用車や社用車がありますか。

| | | 1 ある | 2 ない |
|---|---|---|---|
| Q2S1 | 1. 自家用車(自宅) | ○ | ○ |
| Q2S2 | 2. 社用車(勤務先) | ○ | ○ |

Q3 あなたが自家用車または社用車を運転される頻度をお答えください。

| | | 1 ほぼ毎日 | 2 週4～5日くらい | 3 週2～3日くらい | 4 週1日くらい | 5 2～3週間に1日くらい | 6 1ヶ月に1日くらい | 7 2～3ヶ月に1日くらい | 8 半年に1日くらい | 9 年に1日くらい | 10 それより少ない頻度 | 11 運転しない |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q3S1 | 1. 自家用車(自宅) | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Q3S2 | 2. 社用車(勤務先) | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

Q4 ご自宅の自家用車、勤務先の社用車について、誰も運転せずに自動車を置いたままの時間(空き時間)を、すべてお選びください。ご自宅の自家用車については、平日休日それぞれについて、お答えください。

| | | 1 0時台 | 2 1時台 | 3 2時台 | 4 3時台 | 5 4時台 | 6 5時台 | 7 6時台 | 8 7時台 | 9 8時台 | 10 9時台 | 11 10時台 | 12 11時台 | 13 12時台 | 14 13時台 | 15 14時台 | 16 15時台 | 17 16時台 | 18 17時台 | 19 18時台 | 20 19時台 | 21 20時台 | 22 21時台 | 23 22時台 | 24 23時台 | 25 わからない |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q4S1 | 1. 日】 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| Q4S2 | 2. 日】 | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |
| Q4S3 | 3. 社用車(勤務先) | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ | □ |

Q5 ご自宅または勤務先で、次回自動車を購入する場合は、買い換え、買い足しのいずれになりますか。

| | | 1 買い換え | 2 買い足し | 3 わからない |
|---|---|---|---|---|
| Q5S1 | 1. 自家用車(自宅) | ○ | ○ | ○ |
| Q5S2 | 2. 社用車(勤務先) | ○ | ○ | ○ |

Q6 あなたが普段、最もよく自動車で移動する場面での移動距離はどれくらいですか。最もあてはまるものをお選びください。自分が運転する、同乗する場合に関わらずお答えください。

- ○ 1. 10分以内の買い物等のちょっとした移動
- ○ 2. 30分程度のレジャーや通勤での比較的長い移動
- ○ 3. 上記以外の移動
- ○ 4. 普段、自動車では移動しない

Q7 あなたが普段、最もよく自動車で移動する場面での同乗者を、すべてお選びください。自分が運転する、同乗する場合に関わらずお答えください。

- □ 1. 5歳以下の家族
- □ 2. 6歳以上59歳以下の家族
- □ 3. 60歳以上の家族
- □ 4. 家族以外の友人、知人、同僚
- Q7_5FA □ 5. その他【 】[ ]
- □ 6. 同乗者はいない(一人で乗る)

Q8 自動運転シェアカーは、目的地への到着予定時刻を乗車時にお知らせします。例えば、「14:30に到着予定です」のようなアナウンスがあると想定してください。一般的にはお知らせした到着時間から5分前後ずれて到着しますが、お知らせたした到着時間から必ず1分前後で到着するシェアカーがある場合、一回の利用料金にいくら追加で払えますか。以下よりお選びください。※基本料金は、15分程度の移動で約100円、30分程度の移動で約300円として、普段、最もよく自動車で移動する場面を想定してお考えください。【AC1の選択内容】

- ○ 1. 10円
- ○ 2. 30円
- ○ 3. 50円
- ○ 4. 80円
- ○ 5. 100円
- ○ 6. その他【 】円
- ○ 7. 払いたくない

Q9

自動運転シェアカーは、呼び出してからあなたのいる地点へ移動してきます。基本的には呼び出してからの待ち時間が5分程度ですが、待ち時間が1分のシェアカーがある場合、一回の利用料金にいくら追加で払えますか。以下よりお選びください。※基本料金は、15分程度の移動で約100円、30分程度の移動で約300円として、普段、最もよく自動車で移動する場面を想定してお考えください。【AC1の選択内容】

- ○ 1. 10円
- ○ 2. 30円
- ○ 3. 50円
- ○ 4. 80円
- ○ 5. 100円
- ○ 6. その他【　　】円
- ○ 7. 払いたくない

Q10

自動運転シェアカーを使ってお買い物に行って荷物があるときや、旅行に行くために大きな荷物があるようなときに自動運転シェアカーを使うことを想定してください。一般的な普通車に比べて、荷物を置くスペースが大きくあるような場合、一回の利用料金にいくら追加で払えますか。以下よりお選びください。※基本料金は、15分程度の移動で約100円、30分程度の移動で約300円として、普段、最もよく自動車で移動する場面を想定してお考えください。【AC1の選択内容】

- ○ 1. 10円
- ○ 2. 30円
- ○ 3. 50円
- ○ 4. 80円
- ○ 5. 100円
- ○ 6. その他【　　】円
- ○ 7. 払いたくない

Q11

自動運転シェアカーは運転をする必要がありません。シェアカーの利用者は18歳以上と想定されますが、追加料金を払えば18未満の小学生以上であれば乗ることが可能な場合、一回の利用料金にいくら追加で払えますか。以下よりお選びください。※基本料金は、15分程度の移動で約100円、30分程度の移動で約300円として、普段、最もよく自動車で移動する場面を想定してお考えください。【AC1の選択内容】

- ○ 1. 10円
- ○ 2. 30円
- ○ 3. 50円
- ○ 4. 80円
- ○ 5. 100円
- ○ 6. その他【　　】円
- ○ 7. 払いたくない

Q12

小学生以上の子供だけでも利用可能な自動運転シェアカーがあり、追加料金を払えば子供を乗せた車がどこにいるのか確認できる場合、一回の利用料金にいくら追加で払えますか。以下よりお選びください。※基本料金は、15分程度の移動で約100円、30分程度の移動で約300円として、普段、最もよく自動車で移動する場面を想定してお考えください。あなたと同居している5～18歳のお子様が利用する場合を想定し、お答えください。

- ○ 1. 10円
- ○ 2. 30円
- ○ 3. 50円
- ○ 4. 80円
- ○ 5. 100円
- ○ 6. その他【　　】円
- ○ 7. 払いたくない

Q13

友人や同僚と一緒に同じ場所へ移動しようとしている場合を想定してください。シェアカーは基本的には一人ずつ乗るサービスだとします。ただ追加料金を払えば乗車定員まで複数人で同時に乗車可能な場合、一回の利用料金にいくら追加で払えますか。以下よりお選びください。※基本料金は、15分程度の移動で約100円、30分程度の移動で約300円として、普段、最もよく自動車で移動する場面を想定してお考えください。【AC1の選択内容】

- ○ 1. 10円
- ○ 2. 30円
- ○ 3. 50円
- ○ 4. 80円
- ○ 5. 100円
- ○ 6. その他【　　】円
- ○ 7. 払いたくない

Q14

スマートフォンや、ノートパソコンを持ってシェアカーを利用しようとしている場合を想定してください。追加料金を払えば、充電用のコンセントが利用できる場合、シェアカーの一回の利用料金にいくら追加で払えますか。以下よりお選びください。※基本料金は、15分程度の移動で約100円、30分程度の移動で約300円として、普段、最もよく自動車で移動する場面を想定してお考えください。【AC1の選択内容】

- ○ 1. 10円
- ○ 2. 30円
- ○ 3. 50円

- 4. 80円
- 5. 100円
- 6. その他【　　】円
- 7. 払いたくない

*Q15*

複数のお店を経由して買い物をする場合を想定してください。シェアカーは基本的には、経由地を挟む利用はできず、目的地に着いたら一旦利用が終了するため、手荷物などは毎回下ろす必要あります。追加料金を払えば、買い物が全て終わるまで荷物を下ろす必要がない場合、シェアカーの一回の利用料金にいくら追加で払えますか。以下よりお選びください。※基本料金は、15分程度の移動で約100円、30分程度の移動で約300円として、普段、最もよく自動車で移動する場面を想定してお考えください。【AC1の選択内容】

- 1. 10円
- 2. 30円
- 3. 50円
- 4. 80円
- 5. 100円
- 6. その他【　　】円
- 7. 払いたくない

*Q16*

荷物を下ろす必要がない場合、どれくらいの時間続けて、シェアカーを利用すると思いますか。【AC1の選択内容】

- 1. 1時間程度
- 2. 2時間程度
- 3. 3時間程度
- 4. 4時間程度
- 5. 5時間程度
- 6. 6時間程度
- 7. 7時間程度
- 8. 8時間程度
- 9. 9時間程度
- 10. 10時間以上

*Q17*

旅行等にいくために重く大きな荷物を持っていてシェアカーを利用する場合を想定してください。通常シェアカーの荷物入れは腰に近い高さにあり、荷物によっては積み下ろしし辛い場合があります。ただ追加料金を払えば、荷物を入れる場所が膝よりも低い位置にあり、積み下ろしがしやすい車両を選択できる場合、シェアカーの一回の利用料金にいくら追加で払えますか。以下よりお選びください。※基本料金は、15分程度の移動で約100円、30分程度の移動で約300円として、普段、最もよく自動車で移動する場面を想定してお考えください。【AC1の選択内容】

- 1. 10円
- 2. 30円
- 3. 50円
- 4. 80円
- 5. 100円
- 6. その他【　　】円
- 7. 払いたくない

*Q18*

家が離れた複数の友人と同じ目的地に出かけることを想定してください。追加料金を払えば、全員で集合場所に集まらずに、出発地の異なる友人を拾いながら目的地へ移動可能なサービスが受けられる場合、シェアカーの一回の利用料金にいくら追加で払えますか。以下よりお選びください。※基本料金は、15分程度の移動で約100円、30分程度の移動で約300円として、普段、最もよく自動車で移動する場面を想定してお考えください。【AC1の選択内容】

- 1. 10円
- 2. 30円
- 3. 50円
- 4. 80円
- 5. 100円
- 6. その他【　　】円
- 7. 払いたくない

*Q19*

シェアカーを呼び、自分の前に車両が到着した後、例えば20秒以内に乗車する必要があります。足の骨折等の怪我や、足腰が弱っている場合にシェアカーを利用する際に、利用客の状況によって乗車までの時間を変化させるサービスがあった場合、シェアカーの一回の利用料金にいくら追加で払えますか。以下よりお選びください。※基本料金は、15分程度の移動で約100円、30分程度の移動で約300円として、普段、最もよく自動車で移動する場面を想定してお考えください。【AC1の選択内容】

- 1. 10円
- 2. 30円
- 3. 50円
- 4. 80円
- 5. 100円
- 6. その他【　　】円
- 7. 払いたくない

Q20

足の骨折等の怪我や、足腰が弱っている場合にシェアカーを利用する場合を想定してください。通常はセダンタイプのような車両のような乗りやすさのシェアカーだが、ノンステップバスのように段差が少なく乗りやすさを考慮したシェアカーを選択できる場合、シェアカーの一回の利用料金にいくら追加で払えますか。以下よりお選びください。※基本料金は、15分程度の移動で約100円、30分程度の移動で約300円として、普段、最もよく自動車で移動する場面を想定してお考えください。【AC1の選択内容】

○ 1. 10円
○ 2. 30円
○ 3. 50円
○ 4. 80円
○ 5. 100円
○ 6. その他【　　】円
○ 7. 払いたくない

Q21

車内のつくりについて、お聞きします。シェアカーは基本的には電車のようにシンプルな車内のつくりですが、追加料金を支払えば高級感がある革張りシートでリクライニングが可能なシェアカーを選択できる場合、シェアカーの一回の利用料金にいくら追加で払えますか。以下よりお選びください。※基本料金は、15分程度の移動で約100円、30分程度の移動で約300円として、普段、最もよく自動車で移動する場面を想定してお考えください。【AC1の選択内容】

○ 1. 10円
○ 2. 30円
○ 3. 50円
○ 4. 80円
○ 5. 100円
○ 6. その他【　　】円
○ 7. 払いたくない

Q22 自動運転シェアカーを借りる際に、以下のそれぞれの項目をどの程度重視しますか。【AC1の選択内容】

| | | | 1 重視する | 2 やや重視する | 3 どちらともいえない | 4 あまり重視しない | 5 まった重視しない |
|---|---|---|---|---|---|---|---|
| Q22S1 | 1. | 遅れずに着くこと | ○ | ○ | ○ | ○ | ○ |
| Q22S2 | 2. | 待ち時間が短いこと | ○ | ○ | ○ | ○ | ○ |
| Q22S3 | 3. | 荷物が載せられること | ○ | ○ | ○ | ○ | ○ |
| Q22S4 | 4. | 子供だけでも利用できること | ○ | ○ | ○ | ○ | ○ |
| Q22S5 | 5. | 子供がどこを移動しているか親に連絡がいく | ○ | ○ | ○ | ○ | ○ |
| Q22S6 | 6. | と | ○ | ○ | ○ | ○ | ○ |
| Q22S7 | 7. | 車内で携帯やパソコンが充電ができること | ○ | ○ | ○ | ○ | ○ |
| Q22S8 | 8. | 買い物等の荷物を積みっぱなしにしておける | ○ | ○ | ○ | ○ | ○ |
| Q22S9 | 9. | 荷物の出し入れが容易であること | ○ | ○ | ○ | ○ | ○ |
| Q22S10 | 10. | 複数の目的地を経由できること | ○ | ○ | ○ | ○ | ○ |
| Q22S11 | 11. | 乗り降りが遅くても警告などが出ないこと | ○ | ○ | ○ | ○ | ○ |
| Q22S12 | 12. | 乗り降りがしやすいこと | ○ | ○ | ○ | ○ | ○ |
| Q22S13 | 13. | シンプルで電車のような車内であること | ○ | ○ | ○ | ○ | ○ |
| Q22S14 | 14. | 高級感がありリクライニング可能な革張りシートであること | ○ | ○ | ○ | ○ | ○ |

Q23 シェアカーが普及する世の中になった場合、あなたはどのように車を利用しますか。

○ 1. 自分専用の車を自分だけで使いたい
○ 2. 車を所有し、貸し出したい
○ 3. 所有せず、借りたい

Q24

自家用車の自動運転車をシェアカーとして毎日5時間ずつ貸し出す場合、一ヶ月当りいくら以上の金額が得られれば貸し出しますか。一ヶ月当りに最低得たいと希望する金額を、以下よりお選びください。

○ 1. 3000円
○ 2. 5000円
○ 3. 10000円
○ 4. 15000円
○ 5. 20000円
○ 6. その他【　　】円

Q25

あなたがシェアカーを所有していてその車を貸し出す場合を想定してください。利用客が風邪かインフルエンザを引いていた場合に、あなたは車を貸し出しますか。あてはまるものをお選びください。

○ 1. 普段より高い料金であれば、貸し出しても問題ない
○ 2. 普段どおりで問題ない
○ 3. 貸し出したくない

Q26

前問で「普段より高い料金であれば、貸し出しても問題ない」を選んだ方にお聞きします。普段よりいくらくらい追加でもらえたら、貸し出して問題ないと思いますか。一時間当りに追加を希望する金額を、以下よりお選びください。

- ○ 1. 100円
- ○ 2. 250円
- ○ 3. 500円
- ○ 4. 750円
- ○ 5. 1000円
- ○ 6. その他【　　】円

Q27

あなたがシェアカーを所有していてその車を貸し出す場合を想定してください。　貸し出す車内の清掃について、あなたはどのようにすると思いますか。あてはまるものをお選びください。

- ○ 1. 必要であれば、車内の掃除は自分、あるいは家族などでできる（シェアカー業者には頼まない）
- ○ 2. お金を払わず、シェアカー業者にやってもらいたい
- ○ 3. お金を払ってもシェアカー業者にやってもらいたい

Q28

前問で「お金を払ってもシェアカー業者にやってもらいたい」を選んだ方にお聞きします。　シェアカー業者へ掃除をお願いした場合に、いくらくらいなら、支払ってもよいと思いますか。一回当りの希望する金額を、以下よりお選びください。

- ○ 1. 100円
- ○ 2. 250円
- ○ 3. 500円
- ○ 4. 750円
- ○ 5. 1000円
- ○ 6. その他【　　】円

Q29

あなたがシェアカーを所有していてその車を貸し出す場合を想定してください。学生が利用しようとしていますが、部活帰りで土などで汚れている場合に、あなたは車を貸し出しますか。あてはまるものをお選びください。

- ○ 1. 普段より高い料金であれば、貸し出しても問題ない
- ○ 2. 普段どおりで問題ない
- ○ 3. 貸し出したくない

Q30

前問で「普段より高い料金であれば、貸し出しても問題ない」を選んだ方にお聞きします。普段よりいくらくらい追加でもらえたら、貸し出して問題ないと思いますか。一時間当りに追加を希望する金額を、以下よりお選びください。

- ○ 1. 100円
- ○ 2. 250円
- ○ 3. 500円
- ○ 4. 750円
- ○ 5. 1000円
- ○ 6. その他【　　】円

Q31

あなたがシェアカーを所有していてその車を貸し出す場合を想定してください。飲み会で酔った客が利用しようとした場合に、あなたは車を貸し出しますか。あてはまるものをお選びください。

- ○ 1. 普段より高い料金であれば、貸し出しても問題ない
- ○ 2. 普段どおりで問題ない
- ○ 3. 貸し出したくない

Q32

前問で「普段より高い料金であれば、貸し出しても問題ない」を選んだ方にお聞きします。普段よりいくらくらい追加でもらえたら、貸し出して問題ないと思いますか。一時間当りに追加を希望する金額を、以下よりお選びください。

- ○ 1. 100円
- ○ 2. 250円
- ○ 3. 500円
- ○ 4. 750円
- ○ 5. 1000円
- ○ 6. その他【　　】円

Q33

あなたがシェアカーを所有していてその車を貸し出す場合を想定してください。車内の荷物について、あなたはどうように思いますか。あてはまるものをお選びください。

- ○ 1. 必要であれば、車内の荷物は貸し出す前に車外に出しておく
- ○ 2. 荷物を出したくなく、荷物を載せたままで良いなら貸し出す
- ○ 3. 荷物を載せておけないなら貸し出したくない

Q34

前問で「荷物を載せておけないなら貸し出したくない」を選んだ方にお聞きします。普段よりいくらくらい追加でもらえたら、貸し出して問題ないと思いますか。一時間当りに追加を希望する金額を、以下よりお選びください。

- ○ 1. 100円
- ○ 2. 250円
- ○ 3. 500円
- ○ 4. 750円
- ○ 5. 1000円
- ○ 6. その他【　　】円
- ○ 7. いくらであっても荷物を載せておけないなら貸し出したくない

Q35 最後に、これまでお答えいただいた「自動運転する自動車」や「シェアカー」について、お聞きします。あなたは、これまでお答えいただいた「自動運転する自動車」や「シェアカー」に対して、興味・関心が持てますか。理由もあわせてお答えください。

| | | | |
|---|---|---|---|
| Q35_1FA | ○ | 1. | 興味・関心が持てる ⇒理由：【 】[ ] |
| Q35_2FA | ○ | 2. | やや興味・関心が持てる ⇒理由：【 】[ ] |
| Q35_3FA | ○ | 3. | どちらともいえない ⇒理由：【 】[ ] |
| Q35_4FA | ○ | 4. | あまり興味・関心が持てない ⇒理由：【 】[ ] |
| Q35_5FA | ○ | 5. | 興味・関心が持てない ⇒理由：【 】[ ] |

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