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Impact of introducing the shared autonomous vehicles on Mode Choice and Residential Location Choice behaviors. Case of Taipei metropolitan area, Taiwan

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Topic: **Impact of introducing the shared autonomous vehicles on Mode Choice and Residential Location Choice behaviors. Case of Taipei metropolitan area, Taiwan**

Autonomous technology is improving, and it is about to blend it with our society soon. Among all types of autonomous vehicles, the shared autonomous vehicles (SAVs) could be promising future transport mode in terms of its safety, sustainability, and affordability (Bösch et al., 2018; Litman, 2020). Consequently, the introduction of SAVs will affect the choice of daily transport mode and even likely to change the choice of residential location (Zhang & Guhathakurta, 2018; Gelauff et al., 2019).

Therefore, this research focuses on the changes in mode choice and residential location choice by introducing SAVs. The research question is: How will the shared autonomous vehicles affect the choice of transport modes and residential location in the case of the Taipei metropolitan area?

This thesis consists of seven parts. In the first part, introductions containing the motivation, objectives, and background of the study area will be described. In the second part, literature related to mode choice and residential location choice changes by the introduction of autonomous mobility especially SAVs will be explored in order to have insights into previous research and highlight the relation to this research. In the third part, the methodology of designing a stated preference (SP) survey with the dynamic mode choice and residential location choice experiments, and discrete choice model: Multinomial Logit Model will be introduced. In the fourth part, the descriptive and stated choice experiment analysis of mode choice and residential location choice collected from the SP survey will be described. In the fifth part, the model will be estimated based on collected data in order to investigate potential significant attributes affecting mode choice and residential location choice with the introduction of SAVs. In the sixth part, the model will be applied with existing datasets in order to explore the potential modal shift and relocation behavior with the introduction of SAVs in the case of the Taipei metropolitan area. In the last part, conclusion, discussion, limitation and improvement will be given so that there will be complete further research regarding the impacts of autonomous mobility in any aspect in order to respond adequately to the era of autonomous mobility.

The expected outcome will demonstrate how will mode choice and choice of residential location changes with the introduction of SAVs in the Taipei metropolitan, Taiwan. Besides, the significant attributes that affect the mode choice and choice of residential location will also be highlighted.

The student will present intermediate results to the mentors Dr. Carlos Llorca García and Dr. Ana Tsui Moreno Chou in the fifth, tenth, 15th and 20th week. The student will submit one copy for each mentor plus one copy for the library of the Focus Area Mobility and Transport Systems. Furthermore, the student will provide a PDF file of the master thesis for the website of this research group. In exceptional cases (such as copyright restrictions do not allow publishing the thesis), the library copy will be stored without public access and the PDF will not be uploaded to the website.

The student must hold a 20-minute presentation with a subsequent discussion at the most two months after the submission of the thesis. The presentation will be considered in the final grade in cases where the thesis itself cannot be clearly evaluated.

KuanYeh Chou

Dr. Carlos Llorca García

Student's signature

Dr. Ana Tsui Moreno Chou

Acknowledgment

2020 is a challenging year for the entire world and also for myself. Keep exploring my potential and passion for the expertise of transportation planning, and challenging myself with several transportation-related projects this year. I found myself having a strong sense of mission for building a comfortable, equitable, and sustainable transportation environment for my homeland, Taiwan. Therefore, this research was conducted for providing some insights on the potential future autonomous mobility.

During the journey of my study in Germany, I am being supported and encouraged by my beloved family, filled with full of love by my lovely partner, experienced plenty of exciting events and crazy adventures with my friends, enriched with a fund of knowledge by all the lecturers in TUM especially my erudite and amiable supervisors, learned a brand new mobility philosophy in Urban Standard, etc. All memories and stories will become my energy to propel forward, thank you all, and with a big hug~!

Abstract

Autonomous technology is improving, and it is about to blend it with our society soon. Significantly, the shared autonomous vehicles (SAVs) could be a promising future transport mode in terms of its convenience, sustainability, and affordability. Moreover, SAVs will affect the choice of transport mode and likely to change the residential location. Therefore, this research focuses on exploring: How will the SAVs affect the choice of transport modes and residential location in the case of the Taipei metropolitan area?

In order to answer the research question, the stated preference (SP) survey was designed for mode choice with three alternatives including current mode, SAV without and with ride-sharing, and SAV with ride-sharing with four scenarios combining attributes of SAV fare rate 4 and 8 NTD/km, and waiting time 5 and 10 minutes. The residential location choice is designed for each SAV alternative with four alternatives, including the current alternative, not moving but shift to SAVs, move farther from and move closer to respondents' most frequent trip destination. There are two scenarios consists of SAV fare rate 4 NTD/km and waiting time 5 minutes, and 8 NTD/km and 10 minutes. Besides, the stated choice experiments are designed to show personalized attributes based on respondents' travel and residential characteristics.

With overall 482 and 460 valid responses collected for mode choice and residential location choice, respectively. The multinomial logit models were built for the model estimation. RP-SP combined model and SP model were built for mode choice and indicate that young cohorts are most likely to use SAV without ride-sharing, the old cohorts are most likely to use SAV with ride-sharing. Private car users are most likely to shift to both SAV alternatives, while the users of scooter and bike have the least shift to both SAV alternatives. For the residential location choice, SP models are built for each SAV alternative. With SAV without ride-sharing, people with a lower ratio of monthly travel cost to their monthly household income and with shorter travel time are more likely to relocate closer to their most frequent trip destination. With SAV with ride-sharing, people with a higher ratio of monthly travel cost to their monthly household income and with longer travel time are more likely to relocate farther from their most frequent trip destination. Besides, residents in New Taipei city are more likely to move farther from their most frequent trip destination, and residents in Taoyuan city are more likely to move closer to their most frequent trip destination.

After the model estimation, the case study was conducted by applying the survey data and national travel survey data to mode choice models and survey data to residential location models. The results show that there will be a 5% to 12% shift to SAV without ride-sharing, and 16% to 26% shift to SAV with ride-sharing. For relocation, 2.1% to 3.4% of the entire population will relocate to the suburban area, and 2.1% to 3.6% of the population will relocate to the urban area. Most of the findings are correspond to other related research, and this research can be improved with more sample sizes, detailed data processing, a detailed survey designed, and including more variables and different ways of model estimations.

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List of Abbreviations

AV:	Autonomous vehicle
SAV:	Shared autonomous vehicle
SP:	Stated preference
NTD:	New Taiwanese Dollar
OD:	Origin and destination

Chapter 1. Introduction

In this chapter, firstly, the motivation for conducting this research will be elaborated. Secondly, the Objective and scope of this research will be explained. Thirdly, the current travel and residential location characteristics in the Taipei metropolitan area will be described. Fourthly, the development of autonomous vehicles in Taiwan will be introduced. At last, the research structure of this research will be presented.

1.1 Motivation

Thanks to the emergence of disruptive technology such as 5G, Artificial Intelligent (AI), and Internet of things (IoT). It is promising that vehicles would be capable of connecting to adjacent vehicles and infrastructures, and detecting obstacles to provide optimal and safe journey without human manipulation simultaneously. This vehicle would be very likely to be the new mode of transportation, namely autonomous vehicle (AV). Besides, in the trend of sharing economy, new types of mobility services such as car-sharing, ride-sharing, and car-pooling emerged and have thrived on having a place in current the mobility market. Considering these two emerging trends, the shared autonomous vehicles (SAVs), which is the mode of shared mobility, would very likely to become promising future transport alternative in terms of its safety, sustainability, and affordability (Fagnant & Kockelman, 2016; Krueger et al., 2016; Bösch et al., 2018; Menon et al., 2019; Zhou et al., 2020; Litman, 2020). For the short-term impact of the introduction of the SAVs, the mode choice behavior is expected to be affected directly (Chen & Kockelman, 2016; Krueger et al., 2016; Bansal et al., 2016; Harper et al., 2016; Fagnant et al., 2016; Haboucha et al., 2017; Zhou et al., 2020). For the long-term impact, the introduction of SAVs might have further influence on residential location choice because of the change in travel pattern that results in changing the urban structure (Zhang & Guhathakurta, 2018; Carrese et al., 2019; Gelauff et al., 2019).

In Taipei metropolitan area, Taiwan, where is the densest public transit area, still has the high share of 54.2 % private motorized vehicles including private cars and scooters (Taiwan Ministry of Transportation, 2016). Besides, the energy consumption and CO2 emission of private motorized vehicle is approximately 65% of all transport modes (Taiwan Ministry of Transportation, 2018). Therefore, the introduction of the sharing mobility services combined with autonomous technology is expected to be a prosperous alternative for developing sustainable and human-oriented transportation environment in the Taipei metropolitan area even in the entire nation.

Overall, it is worth investigating how will the mode choice and residential location behavior change by introducing the SAVs. Therefore, this research will emphasize the research question: How will the shared autonomous vehicles affect the choice of transport modes and residential location in the case of the Taipei metropolitan area, Taiwan?

1.2 Objectives and scope

In order to answer the research question, two objectives are set for this research. Firstly, this research aims to explore the users' mode choice and residential location choice preference with the introduction of two SAV alternatives, which are SAVs without ride-sharing and SAVs with ride-sharing, in different travel time and travel cost. Secondly, the potential modal shift and relocation choice in different scenarios will be explored with the existing datasets. Therefore, the socio-demographic characteristics, travel characteristics, and residential location characteristics that are highly significant to the mode choice and residential location choice will be examined and then applied to simulation.

The research scope is in Taipei metropolitan area, which consists of four cities: Taipei City (Capital city), New Taipei City, Keelung City, and Taoyuan City shown in Figure 1, is the heaviest traffic area and has the densest road and public transit network in Taiwan. The population and population density of the four cities of the Taipei metropolitan area is shown in Table 1. The population of the Taipei metropolitan area accounts for almost 40% of the total population of Taiwan (Department of Household Registration, 2019).

Table 1 Population and population density of four cities of the Taipei metropolitan area (Department of Household Registration, 2019)

	Taipei	New Taipei	Keelung	Taoyuan	**Total**
Population (Million)	2.64	4.02	0.37	2.25	**9.28**
Population Density (people/km²)	9,710	1,960	2,790	1,840	**2,520**

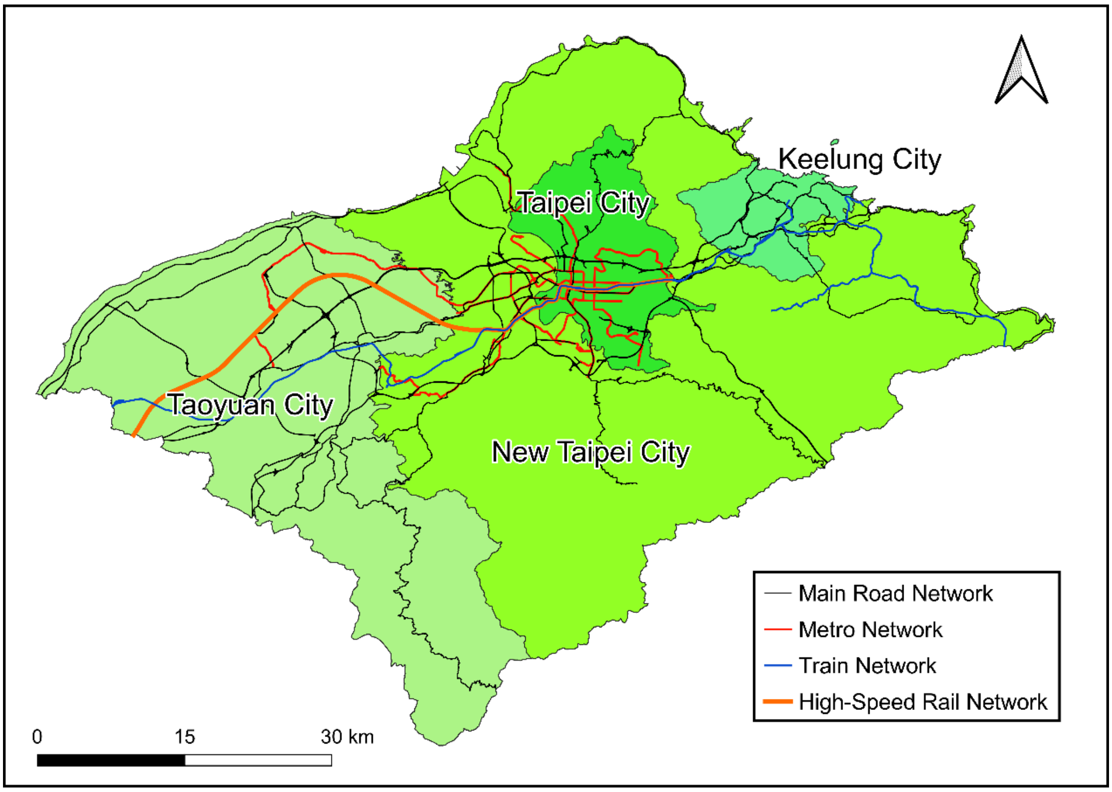

Figure 1 Geographical location of the Taipei metropolitan area

The expected outcomes will be presented with two mode choice models and two residential location choice model. All significant attributes that highly relevant to the mode choices and residential location choices will be demonstrated in the models. Besides, those models will be applied to simulate the modal shift and relocation behavior in the Taipei metropolitan area with the introduction of SAVs.

1.3 Current travel and residential location characteristics

1.3.1 Travel characteristics

Several travel characteristics of residents in the Taipei metropolitan area including trip purposes, modal split, and the current situation of using sharing mobility will be introduced based on national household travel survey conducted in 2016 and other relevant research. Firstly, the trip purposes in cities of the Taipei metropolitan area shown in Table 2 indicate that the commuting trip for work, which accounts for 45% share is the majority. The personal trip, leisure, and shopping trip account for the second-highest share. Furthermore, these four cities have a similar distribution of trip purposes (Taiwan Ministry of Transportation, 2016).

Table 2 Trip purposes in cities of the Taipei metropolitan area (Taiwan Ministry of Transportation, 2016)

Cities	Commute to work	Commute to school	Business	Shopping	Personal activities	Leisure
Taipei	46%	7%	4%	12%	17%	13%
New Taipei	46%	8%	6%	12%	14%	14%
Keelung	46%	7%	2%	15%	18%	13%
Taoyuan	44%	9%	4%	15%	14%	13%
Total	**45%**	**8%**	**5%**	**13%**	**15%**	**14%**

Secondly, the modal split in cities of the Taipei metropolitan area shown in Table 3 indicates that the private motorized vehicles which account for 54% share are the majority. Among the private motorized vehicles, the scooters account for 35% of all modes that reflect the people in the Taipei metropolitan area even in the entire nation have more preference to use scooters than private cars. Public transit has a share of 32.5% that is relatively higher than in other regions in Taiwan because the densest metro and bus network are located in this area. For the active modes with the share of 13%, though the most extensive public bike network is located in this area, there is only the share of 3% among all modes (Taiwan Ministry of Transportation, 2016).

Table 3 Modal split in cities of Taipei metropolitan area (Taiwan Ministry of Transportation, 2016)

	Private mode		Public transit					Active mode	
Cities	Private car	Scooter	Metro	Bus	Train	High-speed rail	Taxi	Bike	Walk
Taipei	14%	25%	18%	17%	1%	0.3%	7%	4%	13%
New Taipei	17%	37%	13%	14%	2%	0.8%	3%	3%	9%
Keelung	20%	28%	5%	23%	4%	0%	7%	1%	11%
Taoyuan	27%	47%	2%	8%	3%	0.2%	1%	2%	9%
Total	**18%**	**35%**	**12%**	**14%**	**2%**	**0.5%**	**4%**	**3%**	**10%**
	54%		**32.5%**					**13%**	

Thirdly, regarding sharing mobility in the Taipei metropolitan area. For this research, the current situation of using sharing mobility such as car-sharing, ride-sharing, and scooter sharing in the Taipei metropolitan area can be the precedent of the expected acceptance of SAVs. Sharing mobility in Taiwan still has space to grow, although there are already exist several sharing mobility providers and services. Statista (2018) organized the usage of shared mobility services such as car-sharing, scooter-sharing, ride-sharing, and bike-sharing among 1,935 respondents in Taiwan in 2018. The result shown in Table 4 indicates that approximately 93% of all respondents have an awareness of at least one of the shared mobility services, and approximately 47% have used at least one of them.

Table 4 Usage of shared mobility services (Statista, 2018)

	Car-sharing (Zipcar)	Scooter-sharing (Wemo)	Ride-sharing (Uber)	Bike-sharing (Obike)
Usage rate (%)	5.2%	5.6%	23.7%	12.6%

Besides, Hsiao (2018) also surveyed to investigate the most potential acceptance group using car-sharing services in the Taipei metropolitan area. Hsiao (2018) classified the respondents in four user groups which have preferences toward service quality, environmental awareness, privacy, and the equally-preferred user group. The result shows that the equally-preferred user group, which is 34% among all 400 respondents has the highest willingness of 83% to use the car-sharing services. Most of the respondents in the equally-preferred user group are under 30 years old. Besides, Hsiao (2018) indicates that almost 50% of the respondents would like to give up their car to use car-sharing services if there is a comprehensive development of car-sharing services. Chen et al. (2017) also summarized that the potential user group of car-sharing services are students, young commuters, the elderly, and foreign tourists.

Therefore, Hsiao (2018) shows that car-sharing services in the Taipei metropolitan area have great potential to rise. The ministry of transportation targets to increase the usage of sharing mobility and put more emphasis on promoting Mobility as a Service (MaaS) that integrates sharing mobility with public transit from 2020 (Taiwan Ministry of Transportation, 2019). Moreover, those targets are also paving the way for making more users get familiar with sharing mobility and increase the acceptance of the SAVs in the future era of autonomous mobility.

1.3.2 Residential location characteristics

Regarding the relationship between residents' residential location and their commuting location, typically workplace or school, among four cities in the Taipei metropolitan area that shown in Table 5. 14% of residents in Taipei City commute across cities, while 40% and 49% of residents in New Taipei City and Keelung City, respectively, have the highest ratio of commuting across the cities (Taiwan Ministry of Transportation, 2016). This trend is because Taipei City has the most jobs and education opportunities among four cities in the Taipei metropolitan area, so that attracts many residents from other cities.

Table 5 Residents' commuting location among cities in the Taipei metropolitan area (Taiwan Ministry of Transportation, 2016)

Residents' Cities	Same City		Across Cities
	Same District	Different Districts	
Taipei	34%	52%	14%
New Taipei	38%	22%	40%
Keelung	27%	24%	49%
Taoyuan	57%	32%	11%
Total	**40.4%**	**37.3%**	**22.4%**

Besides, the housing and rent price also largely influences the residential location choice and ways of commuting. The housing and rent price which shown in Table 6 indicates that Taipei city has the highest housing and rent price among four cities in Taipei metropolitan area, while other cities are cheaper (Sinyi, 2020; CBCT,2020; HouseFun,2020).

Chen (2003) conducted the survey that explored the attributes that influence the choice of residential location and workplace in the Taipei city and New Taipei city. The results show that the convenience of transportation and affordable living cost are the significant attributes for both choices of residential location and workplace. Most of the residents need to do a trade-off between these two attributes. Therefore, residents who are not able to afford high living cost choose to live in other cities, especially in New Taipei City, where is close to Taipei City that spends more commuting time. In comparison, residents who can afford high living cost usually tend to move to Taipei City to spend less commuting time.

Table 6 Range of housing and rent price of cities in the Taipei metropolitan area (Sinyi, 2020; CBCT,2020; HouseFun,2020)

Cities	Housing price range (NTD/m²)	Rent price range (NTD/m²/month)
Taipei	146,000 - 265,000	960 – 1,350
New Taipei	18,000 – 144,000	300 – 920
Keelung	40,000 – 58,000	450 - 700
Taoyuan	27,000 – 67,000	250 - 680

1.4 Development of autonomous vehicle in Taiwan

Autonomous vehicle (AV) is also known as Driverless car and Self-driving car, which is capable of driving itself from a starting point to a pre-determined destination without human intervention. SAE International classifies the levels of automation of AV from no driving autonomation (level 0) to full driving automation (level 5) (SAE International, 2019). In 2020, Taiwan ranked as 13th in autonomous vehicles readiness index published by KPMG in terms of four pillars: policy and legislation, infrastructure, technology and innovation, and consumer acceptance (Threlfall, 2020), Table 7 shows the contemporary development of autonomous vehicle in Taiwan in terms of the four pillars above.

In the aspect of policy and legislation, the Taiwan government legislated the Unmanned Vehicles Technology Innovation Experimentation Act in December 2018. The regulation provides AV with a regulatory sandbox that enables testaments to the actual roadway (TAIPEI TIMES, 2018).

In the aspect of infrastructure, in February 2019 followed by the legislation of the AVs, Taiwan CAR Lab, which is the closed AVs' experimentation field, was established for testing the AVs. Moreover, companies from all around the world are also welcomed to test their AVs (Taiwan CAR Lab, 2019).

In the aspect of technology, autonomous Minibus WinBus is the first domestic autonomous electric minibus made by Automotive Research & Testing Center (ARTC) (ARTC, 2019). WinBus has level 4 automation that is capable of operating autonomously in most of the roadway and environmental conditions (SAE International, 2019). Furthermore, autonomous bus Turing, which the hard-ware of the bus is made domestically, has automation level between 3 to 4 (Turing, 2020). Turing autonomous bus will start a testament on the open road at night for the simulation of night service in September 2020, and the testament will open to the public (Turing, 2020).

In the aspect of consumer acceptance, The report of KPMG Threlfall (2020), used civil society technology use, consumer ICT adoption, internet users, mobile broadband subscriptions, and the usage of ride-hailing services to calculate the consumer acceptance index. However, there is no first-hand information of user acceptance of autonomous mobility. Therefore, this research is intended to have more insight into the user acceptance of autonomous mobility focusing on the shared autonomous vehicles.

Table 7 Contemporary development of autonomous vehicle in Taiwan

Timeline	Development
12. 2018	Legislation of Unmanned Vehicles Technology Innovation Experimentation Act
02. 2019	Establishment of Taiwan CAR Lab
06. 2019	Implementation of Unmanned Vehicles Technology Innovation Experimentation Act
08. 2019	Introduction of the first domestic autonomous electric minibus
09. 2020	Turing Autonomous Bus plan to have public testament on the open road for providing the night service.

1.5 Research structure

This research consists of seven parts which are shown in Figure 2. In the first part, introductions containing the motivation, objectives, and background of the study area will be described.

In the second part, literature related to mode choice and residential location choice changes by the introduction of autonomous mobility especially SAVs will be explored in order to have insights into previous research and highlight the relation to this research. The research gap that this research intended to fill will also be described.

In the third part, the methodology of designing a stated preference (SP) survey with the dynamic mode choice and residential location choice experiments, and discrete choice model: Multinomial Logit Model will be introduced.

In the fourth part, the descriptive and stated choice experiment analysis of mode choice and residential location choice will be described with the data collected from the SP survey.

In the fifth part, the model will be estimated based on collected data in order to investigate potential significant attributes affecting mode choice and residential location choice with the introduction of SAVs.

In the sixth part, the model will be applied with existing datasets in order to explore the potential modal shift and relocation behavior with the introduction of SAVs in the case of the Taipei metropolitan area.

In the last part, discussion on main findings, conclusion, limitation and improvement will be given so that there will be complete further research regarding the impacts of autonomous mobility in any aspect in order to be well-prepared for the era of autonomous mobility.

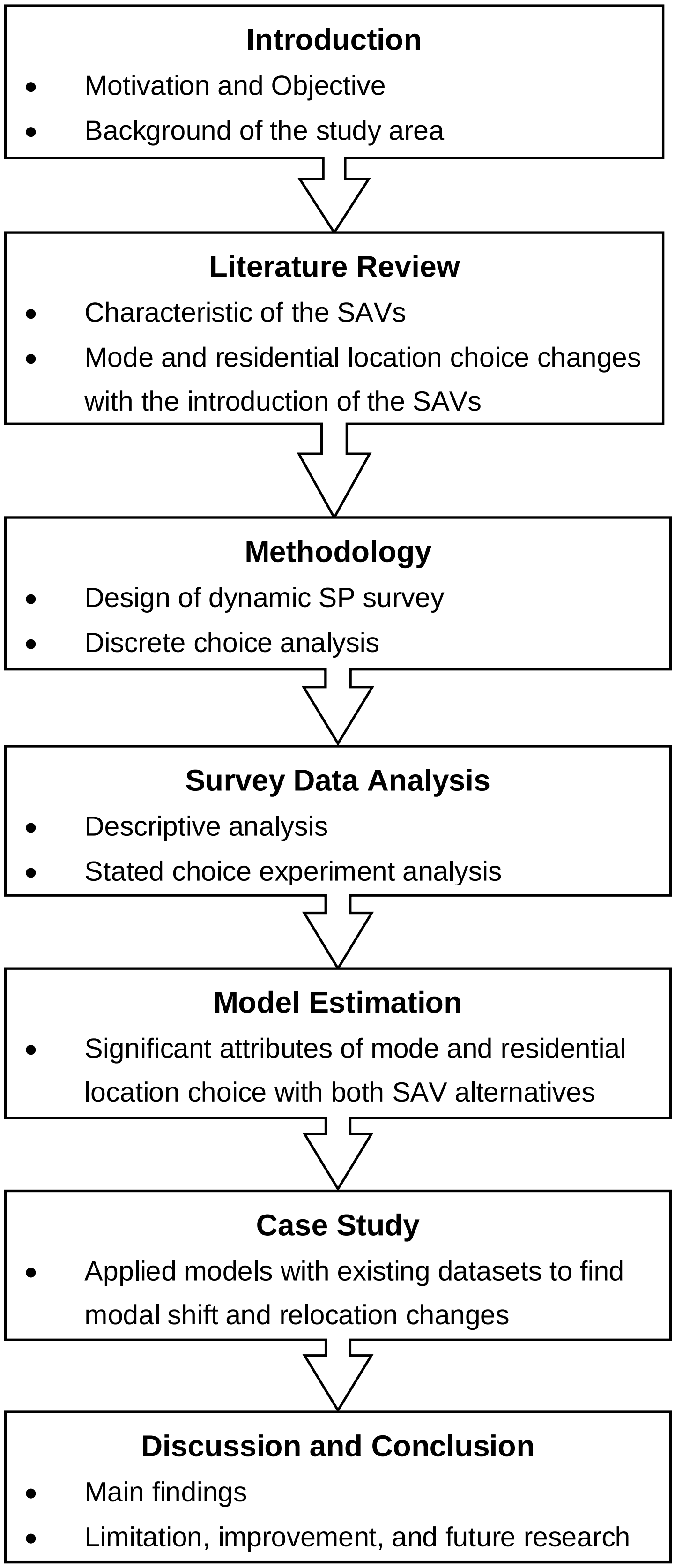

Figure 2 Research structure

Chapter 2. Literature Review

In this chapter, the research regarding the mode choice and residential location choice by the introduction of the shared autonomous vehicles (SAVs) will be elaborated. Besides, the research gap of previous studies that this research intends to fill will be identified. Regarding the structure of this chapter, firstly, the characteristics of the SAVs will be introduced to have a clear insight into this future transportation mode. In the second and third sections, the mode choice and residential location choice behavior by introducing the SAVs will be described in terms of study areas, data sources, analytical methods including alternatives and significant attributes, and research findings. At last, the research gap that this research intended to fill will be explained.

2.1 Characteristics of the Shared Autonomous Vehicles

The SAVs is a type of autonomous vehicles (AVs) that combine autonomous technology with conventional car-sharing and taxi services. Thus the SAV is also called as an autonomous taxi, driverless taxi or autonomous on-demand service (Fagnant & Kockelman, 2014, 2015; Wilson, 2015; Iglesias et al., 2017; Vosooghi et al., 2019). There are several characteristics of the SAVs, and this research will categorize them into four categories in this section, including services, cost, traffic, and sustainability.

Regarding the services, the SAVs are expected to provide on-demand services without access time. SAVs will directly pick passengers up at their origin place when they reserve the SAV in advance via mobile applications or other platforms (Fagnant & Kockelman, 2016; Greenblatt & Shaheen, 2015; Menon et al., 2019; Zhou et al., 2020). Without access time to vehicles will be beneficial especially to mobility disabled people such as the elderly, children, disabled people, and the people in rural areas where are hard to access public transit services (Harper et al., 2016; Schmargendorf et al., 2018). Therefore, the usage of the SAVs is expected to increase compared to conventional car-sharing services since the distance of accessing the vehicle is seen as a crucial determinant of the usage of the car-sharing services (Jing et al., 2019). Moreover, the SAVs are also expected to provide a last-mile solution for public transit users that facilitates multimodal transport (Krueger et al., 2016; Wen et al., 2018; Shen et al., 2018; Menon et al., 2019).

Regarding the cost, the SAVs are expected to have lower cost compare to private cars since the users do not need the car ownership, thus save the cost of purchasing the car, fuel, maintenance, parking as well as depreciation (Howard & Dai, 2014; Schoettle & Sivak, 2015; Wilson, 2015; Cohen & Shaheen, 2016; Hawes, 2017; Menon et al., 2019). Among all the costs of owning private cars, depreciation cost accounts for the highest costs (Jing et al., 2019). Furthermore, the SAVs also has the potential to provide ride-sharing services that two or more users, who have similar destinations, can be allocated and share a single SAV. As a result, the cost will be even lower than the cost of SAV with a single user (Fagnant & Kockelman, 2016; Wilson, 2015; Menon et al., 2019).

Regarding the traffic, though the SAVs are likely to reduce private car ownership, the changes of vehicle kilometer traveled (VKT) depends on the induced trips, vehicle relocation trips, i.e., empty vehicle trips, occupancy rate, and substitution of public transit. The VKT is expected to increase when there are high induced trips, vehicle relocation trip, or public transit services are substituted by the SAVs (Chen & Kockelman, 2016; Fagnant et al., 2016; Krueger et al., 2016). In contrast, VKT is expected to decrease when there are higher occupancy rate, proper pricing schemes, and provide first- and last-mile services that connect to public transit (Fagnant & Kockelman, 2016; Shen et al., 2017; Winter et al., 2018; Menon et al., 2019; Zhao & Malikopoulos, 2019).

Regarding the sustainability and safety, the SAVs are expected to have a less environmental impact than the private cars since the SAVs can reduce the car ownership and have higher utilization rate especially with the ride-sharing services in the high occupancy rate condition. Therefore, energy use and greenhouse gas emission (GHG) are expected to be mitigated (Fagnant & Kockelman, 2016; Greenblatt & Shaheen, 2015; Menon et al., 2019). However, the large number of modal shift from public transit to the SAVs will result in an increase in energy use and GHG emission (Krueger et al., 2016).

2.2 Mode choice behavior by introducing SAV

The research of the mode choice behavior by introducing the SAVs is a new and emerging topic. Thus, the research regarding this topic is relative rare than other research topics. This section will introduce research regarding the topic above, including research from worldwide outside Taiwan and research from Taiwan. At the end of this section, the summary of the literature regarding this topic will be shown in Table 8.

There is four research from worldwide outside of Taiwan. Firstly, Krueger et al. (2016) conducted a stated choice experiment in Australia to explore how the SAVs and the ride-sharing will be adopted. Respondents were asked to choose their mode for a reference trip among three alternatives, including SAV without ride-sharing, SAV with ride-sharing, and respondents' current used mode. Two SAV alternatives are considered as two independent modes. All three alternatives were specified by three attributes, including travel cost, waiting time, total travel time. Attributes' value of SAV with and without ride-sharing alternatives varied depends on the respondents' current travel characteristics which are previously answered. Afterwards, the mixed-logit model was used to analyze the stated preference (SP) survey of overall 435 respondents. The result shows that all three attributes above are significant determinants for adopting the SAVs and ride-sharing service, and young cohorts and multimodal travelers may be more probable to adopt the SAVs. Similar to Krueger et al. (2016), this research uses the identical alternatives, attributes, and data collection method, i.e., SP survey with the dynamic value of attributes varied depends on each respondents' travel characteristic, with application to the Taipei metropolitan area.

Secondly, Haboucha et al. (2017) also conducted a stated choice experiment in Israel and North America to explore how the private and shared AVs will be adopted. Respondents who own cars were asked to choose their mode for a commuting trip among three alternatives including purchase private AV, subscription to annual SAV, and conventional cars they already in use. All three alternatives were specified by four attributes, including vehicle purchase cost, annual subscription cost, travel cost, and parking cost. Attributes' value of private AV and SAV alternatives varied depends on the respondents' current travel characteristics which are previously answered. Besides, respondents' attitudes toward the environment, public transit, new technology, AV, safety, enjoy driving, and appreciation of car feature were asked as latent variables. Afterwards, the nested logit kernel model was used to analyze the SP survey of overall 721 respondents. The result shows that 44% of respondents remain choosing their current conventional cars, and the potential AV adopters may more likely to be the young cohorts, more educated people, and travelers with longer time in vehicles. Regarding attitudinal factors, three latent variables, including environmental concern, enjoy driving, and attitude toward AV are significant when estimating choice decision. Moreover, Israelis are generally more likely to adopt AV than North American. Similar to Haboucha et al. (2017), this research uses the SP survey with the dynamic value of attributes varied depends on each respondents' travel characteristic.

Thirdly, Winter et al. (2018) also conducted a stated choice experiment in the Dutch urban area to explore how the free-floating car-sharing (FFCS) and SAVs will be adopted. Respondents were asked to choose their mode for fictitious commuting or educational trip with a fixed distance of 8 kilometers among five alternatives including FFCS, SAV, taxi, bus, and own vehicle. All five alternatives were specified by six attributes including trip cost, parking cost, access and egress time, waiting time, in-vehicle time, parking searching time with three attribute levels. Afterwards, the multinomial logit model and nested logit models with two categories were used to analyze the SP survey of overall 732 respondents to capture vehicle automation or vehicle ownership. The result shows that early adopters whose household have the subscription of ride-sharing or car-sharing services are most preferred to use SAV than other modes. In contrast, normal and late adopters hold repulsive attitude toward using the SAVs. Similar to Winter et al. (2018), this research uses the SP survey and try to fill the research gap by including more trip purposes and different trip durations.

At last, Zhou et al. (2020) also conducted a stated choice experiment in Australia to explore how the car-sharing and the SAVs will be adopted. Respondents were asked to choose their mode for recent trips among six out of ten alternatives including future transport mode (future vehicle and future two-wheeler), and currently available modes (car-sharing, shared two-wheeler, taxi, public transit, bike and walk, current vehicle, current tow-wheeler, and employer's vehicle). All ten alternatives were specified by six attributes, including vehicle size, operating cost, purchase cost, average peak waiting, self-driving, and policy incentive. Afterwards, the random parameter logit model was used to analyze the SP survey of overall 1,433 respondents to explore preference heterogeneity. The result shows that users with car-sharing experience are more likely to use diversified modes, while less likely to use private mode. Furthermore, female, non-drivers, and the elderly hold negative perception toward SAVs.

For the research regarding mode choice changes by introducing autonomous mobility in Taiwan, Though there is no research regarding SAV's choice behavior, there is one similar research regarding this topic. Yu (2019) explores how will the introduction of the autonomous bus has influences on the modal split in the Taipei Metropolitan area in 2025. This research is the first study that included scooters as an alternative to explore mode choice changes by introducing autonomous mode in Taiwan. Five traditional modes: private car, scooter, bus, metro, and bike are included in the model, combining autonomous bus with four different pricing schemes: Flat Fare, Distance-Based I, Distance-Based II and On-demand Service as estimating scenarios. All six modes were specified by five attributes, including in-vehicle time, out-of-vehicle time, the value of in-vehicle time, average speed, and travel cost. Afterwards, a multinomial logit model was applied to analyze the potential modal shift by applying distance matrix data of each traffic zone in the Taipei metropolitan area obtained from previous research to utility function. Results show that the modal split of the autonomous bus in these four scenarios, namely Flat Fare, Distance-Based I, Distance-Based II and On-demand Service are: 6%, 2%, 7% and 11%, respectively. Besides, the modal split of the autonomous bus is sensitive to vehicle speed, out-of-vehicle travel time, flat-fare, and monetary cost per kilometer. However, there is a limitation that the result of potential modal shift hardly reflects the mode choice behavior in reality. Therefore, in order to extend the study of the impact of autonomous mobility on mode choice such as Yu (2019), this research will fill the research gap by conducting SP survey to reflect more realistic mode choice behavior toward sharing and autonomous mobility.

To sum up, most of the literature indicate that attributes such as travel cost including purchase, parking, operation and maintenance cost, travel time including in- and out-of-vehicle time and waiting time, and feature of the vehicle including vehicle size probably will be curial factors that decide whether people will adopt the SAV or not. Moreover, the SAVs are generally expected to be adopted more likely by the young generation and early adopters.

Table 8 Summary of the research regarding mode choice behavior by introducing the SAV and autonomous mobility

Research	Study area	Data collection method	Alternatives	Significant attributes
Krueger et al. (2016)	Australia	SP survey with personalized attribute value	• SAV without ride-sharing • SAV with ride-sharing • Current used mode	• Travel cost • Waiting time • Total travel time
Haboucha et al. (2017)	Israel & North America	SP survey with personalized attribute value	• Private AV • SAV • Current owned vehicle	• Vehicle purchase cost • Annual subscription cost • Travel cost • Parking cost Attitude toward: • Environment • Public Transit • New technology • AV • Safety • Enjoy driving • Car feature
Winter et al. (2018)	The Netherlands	SP survey with fixed attribute value	• SAV • Free-floating car-sharing • Taxi • Bus • Current owned vehicle	• Trip cost • Parking cost • Access and Egress time • Waiting time • In-vehicle time • Parking searching time
Zhou et al. (2020)	Australia	SP survey with personalized attribute value	• Future modes: Future vehicle and Future two-wheeler • Current modes: Car-sharing, Shared two-wheeler, Taxi, Public transit, Bike and Walk, Current vehicle, Current tow-wheeler, and Employer's vehicle	• Vehicle size • Operating cost • Purchase cost • Average peak waiting time • Self-driving • Policy incentive
Yu (2019)	Taiwan	From previous research	• Traditional modes: Car, Scooter, Bus, Metro, and Bike • Autonomous Bus	• Travel cost • Value of In-vehicle time • Out-of-vehicle time • In-vehicle time • Average speed

Research	Model	Key findings
Krueger et al. (2016)	Mixed Logit Model	• Travel cost, Waiting time, and Total travel time significantly affect the adoption of SAVs. • Young cohorts and multimodal travelers are more likely to adopt the SAVs.
Haboucha et al. (2017)	Nested Logit Kernel Model	• Young cohorts, educated people, and travelers with longer time in vehicles are more likely to adopt the SAVs. • Environmental concern, enjoy driving, and attitude toward AV are significant when estimating choice decision. • Israelis are overall more likely to adopt AVs than North American.
Winter et al. (2018)	Multinomial Logit Model + Nested Logit Model	• Early adopters are most preferred to use SAV than other modes, while normal and late adopters hold repulsive attitude toward using the SAVs.
Zhou et al. (2020)	Random Parameter Logit Model	• Users with car-sharing experience are more likely to use diversified modes and less likely to use private mode. • Female, non-drivers, and the elderly hold negative perception toward SAVs.
Yu (2019)	Multinomial Logit Model	• The autonomous bus will gain the share of 6%, 2%, 7% and 11%, in the scenarios of Flat Fare, Distance-Based I, Distance-Based II and On-demand Service respectively.

2.3 Residential location choice behavior by introducing SAV

There is also little research about how will the introduction of SAVs affect the residential location choice worldwide neither in Taiwan. Therefore, this section will introduce four research regarding this topic. At the end of this section, the summary of the literature regarding this topic will be shown in Table 9.

Firstly, Bansal et al. (2016) also explores the changes in residential location choice with the hypothesis that SAVs become prevalent in Austin, US. 347 respondents conducted the public opinion survey. After weighted the samples to match the population of Austin, 74% would like to stay at the same location, 12% would like to move farther from central Austin, and 14% would like to move closer to central Austin. Furthermore, the ordered probit model was applied to estimate what attributes are significant for location-shift decisions. Attributes including a people who have a larger number of children, live farther from the workplace with higher employment density or higher household density neighborhoods, drive alone to work, and with higher education level are predicted to move farther from central Austin. This trend is because they desire for relatively lower house price in the suburban area. In contrast, attributes including males of full-time worker with higher income and VMT, and who and smartphone and familiar with car-sharing are predicted to move closer to central Austin. This trend is because they want to enjoy the high-density and low-cost SAV services.

Secondly, Zhang & Guhathakurta (2018) explores the changes in residential location choice with the hypothesis that SAVs become prevalent in the Atlanta metropolitan area, US. The travel survey data of Atlanta containing current home location preference and home sales data containing trend of real estate development are used to build the residential location choice model applied with multinomial logit model and then integrated existing agent-based SAV simulation model to simulate future potential relocation changes. After the simulation, the attributes of property age, the ratio of the property price to annual household income, percentage of the same race, commute time cost which is commute time multiplied salary, and ratio of commute vehicle cost to annual income are all significant to all four segments of whether respondents are older than 40 and whether respondents have kids. The attribute of the proximity to the middle school is also a significant factor to all segments except age under 40 without kids. Therefore, the result indicates that most of the household may relocate farther away from their workplaces to the cheaper property with schools surrounding due to the decrease in commute costs. The younger generation is likely to move farther from the city center while the older generation is likely to move slightly closer to the city center to reduce waiting time. Overall, the household that prefers to move farther from the city center is still the majority; thus, the introduction of the SAV may result in the urban sprawl.

Thirdly, Carrese et al. (2019) explores the changes in residential location choice with the hypothesis that AVs become prevalent in Rome, Italy. The SP survey was conducted with two alternatives, including the stay at the same location and move farther to the suburban area with 201 respondents. Furthermore, the binary model was applied to estimate what attributes are significant for location-shift decisions. Attributes including the influence of AV on relocation with three Likert scales including very important to not important, current residence inside zone 1 where is the city center, and Historic willingness to relocate calculated as the logarithm of the number of respondent's residential locations in last ten years are significant. The result indicates that residents live in the city center are more likely to move to the suburban area than residents who live between the city center and suburban area, which may result in suburbanization. Similar to Carrese et al. (2019), this research also uses SP survey and fill the research gap by including more attributes such as travel time, travel cost, and property cost in order to build more sophisticated residential location choice model.

At last, Gelauff et al. (2019) explores the changes in residential location choice with the hypothesis that cars and public transit with high and full automation become prevalent in the entire Netherlands. Statistics Netherlands provided data with home, job and commuting choice, land prices and amenities to estimate the home location choice model by logit model. There are six scenarios that each of high automation (SAE Level 4) and full autonomation (SAE Level 5) context has three scenarios including private car automation, public transit automation, and mixed automation of private car and public transit. Besides, in a high automation scenario, public transit is considered as SAV. Attributes, including accessibility to jobs, land rent, and proximity to home location amenities (i.e., the park, restaurant, and cultural amenities), are significant. The result indicated that in both high and full automation scenarios, private car automation might result in suburbanization, while public transit automation may attract population to urbanized areas. Combination of the private car and public transit may result in the concentration of population in both cities and suburbs of highly urbanized areas. In contrast, the population may decrease in lower urbanized cities and suburbs. The higher the automation level, the more obvious of this trend.

To sum up, most of the literature related to residential location choice behaviors after the introduction of the SAV indicate that attributes travel time (i.e., distance from the workplace, commute time, and job accessibility), Property cost (i.e., Land rent), Area of residence, and household income probably will be crucial factors for residential location choice in AV era. Moreover, suburbanization caused by urban sprawl due to the convenience of AV and lower house price is the most likely trend after the prevalence of AV that some research above and other research (Zakharenko, 2016; Heinrichs, 2016; Anderson et al., 2016; Litman, 2020) proposed. However, full-time worker male, tech-savvy, elderly, and people surrounding with higher public transit automation might tend to move closer to the city center.

Table 9 Summary of the research regarding residential location choice behavior by introducing the SAV and autonomous mobility

Research	Study area	Data collection method	Alternatives	Significant attributes
Bansal et al. (2016)	Austin, US	Public opinion survey	• Stay at current residential location • Move father from city center • Move closer to city center	• Annual VMT • Drive alone for work trip • Distance from workplace • Area type • Employment density • Household density • Gender • Number of children • Education level • Employment status • Annual household income • Carry smart phone • Familiar with car-sharing
Zhang & Guhathakurta (2018)	Atlanta, US	Atlanta travel survey data & Home sales data	• Choose among 30 randomly selected housing unit which are transacted within one year	• Property age • Property price - Household annual income ratio • Same race percentage • Commute time * Salary • Commute vehicle cost - Household annual income ratio • School surrounding
Carrese et al. (2019)	Rome, Italy	SP survey with fixed attribute value	• Stay at current residential location • Move father from city center	• Influence of AV on relocation • Current residence area • Historic willingness to relocate
Gelauff et al. (2019)	The Netherlands	Data from Statistics Netherlands	• Choose among 3,500 home locations	• Accessibility to jobs • Land rent • Proximity to home location amenities (i.e., Park, restaurant, cultural amenities)

Research	Model	Key findings
Bansal et al. (2016)	Ordered Probit Model	• People with a larger number of children, live farther from the workplace with higher employment density or higher household density neighborhoods, drive alone to work, and with higher education level are predicted to move farther from central Austin. • Males of full-time worker with higher income and VMT, and who and smartphone and familiar with car-sharing are predicted to move closer to central Austin.
Zhang & Guhathakurta (2018)	Segmented Multinomial Logit Model (Residential location choice) + Agent-based mode (SAV simulation)	• Most of the households may relocate farther away from their workplaces with school and amenities surrounding due to the decrease in commute costs that may result in urban sprawl. • The younger generation is likely to move farther from the city center. In comparison, the older generation is likely to move slightly closer to the city center to reduce waiting time.
Carrese et al. (2019)	Binary Logit Model	• Residents who live in the city center are more likely to move to the suburban area than residents who live between the city center and suburban area.
Gelauff et al. (2019)	Logit Model	• Private car automation may result in suburbanization, while public transit automation may attract population to urbanized areas. • Combination of the private car and public transit automation may result in the concentration of population in both cities and suburbs of highly urbanized areas. In contrast, the population may decrease in lower urbanized cities and suburbs.

2.4 Research needs of literature

After summarizing the literature regarding mode choice and residential location choice by the introduction of SAV or AV, this section will describe the research gaps that this research intends to fill.

First and most important of all, this research tries to configure the preliminary knowledge of modal choice, and residential location choice behaviors in the era with SAVs are prevalent since none of the research regarding this topic has been done in Taiwan. Yu (2019) 's research of the modal split of the autonomous bus in the Taipei Metropolitan area in 2025 laid a solid foundation for this research, and data with more accuracy regarding actual perception toward autonomous mobility will be collected by SP survey.

Secondly, regarding the way of designing the stated choice experiment for mode choice, this research will use dynamically personalized attribute values varied depends on each respondents' travel characteristics in the SP survey that is identical to Krueger et al. (2016), Haboucha et al. (2017), and Zhou et al. (2020). However, the mode choice models of research above are either using alternatives between current mode and SAVs (i.e., SP model) or alternatives among all conventional modes and SAVs (i.e., RP-SP combined model). Therefore, this research will estimate both SP and RP-SP combined models to explore more detailed modal split and the extent of mode shift from each mode to each SAV alternative. Moreover, in addition to the survey data, national household travel survey data will also be used to apply to models in order to have more insight on the difference of modal shift and the way of extrapolating attributes with different datasets. None of these processes has been done in all previous research.

At last, regarding the way of designing the stated choice experiment for residential location choice, common significant attributes for all previous research are included. The attributes' value will also be dynamically personalized depends on each respondent. Besides, this research will explore the residential location choice related to respondents' most frequent trip destination not just only limited to workplace and school thus the respondents' relocation behavior will be examined more representatively for people with diverse travel characteristics. All processes above have not been done in all previous research.

To sum up, the results of this research will be compared to the research findings of the literature that have been elaborated in this chapter. The similarity and the difference between this research and previous research will be discussed in terms of the study area, data sources, methodology, and model estimation.

Chapter 3. Methodology

In this chapter, the methodology of designing stated choice experiments of mode choice and residential location choice, the discrete choice analysis, and the finalization of stated preference (SP) survey after pilot study will be described. Firstly, the design of the entire survey structure and the way of designing stated choice experiments of mode choice and residential location choice will be elaborated respectively. Secondly, the discrete choice analysis used to estimate the mode choice and residential location choice models are described.

3.1 Stated preference survey

In order to have insights into the mode choice and residential choice behaviors by introducing SAVs, the stated preference (SP) survey is designed to obtain more realistic data. Therefore, this section will elaborate on the entire survey structure, design of stated choice experiment for mode choice and residential location choice, and finalization of the survey after the pilot survey.

3.1.1 Survey structure design

The survey was developed in “LimeSurvey” which is open source and web-based on-line survey application. The survey structure shown in Figure 3 consists of the travel characteristics including current travel behavior and perception toward sharing and autonomous mobility, residential location characteristics including current residential location and most frequent trip destination, stated choice experiments including mode and residential location choice, and socio-demographic characteristics. The complete designed survey form is shown in Appendix .

Travel Characteristics

Current travel behavior:

- Most frequent trip purpose, Mode, Travel time (access&egress time, waiting time, in-vehicle time), Travel cost (fare cost, parking cost)

Perception toward sharing and autonomous mobility:

- Awareness of and interest in car-sharing, ride-sharing, autonomous vehicle (AV), and shared autonomous vehicle (SAV)

↓

Residential Location Characteristics

Current residential location:

- Cities and districts of residence, Property type (Own or rent), Property price, Reasons affecting current residential location choice

Most frequent trip destination:

- Cities and districts of the most frequent trip destination

↓

Stated Choice Experiments

Introduction of SAVs

Mode choice:

- Choice among the current mode and two SAV alternatives inluding SAV without and with ride-sharing in 4 scenarios with different SAV fare and waiting time

Residential location choice:

- Choice among the current residential location and three alternatives with SAV without ride-sharing including not moving, moving farther from and closer to the most frequent trip destination in 2 scenarios with different property cost, monthly travel cost, and travel time
- Choice among the current residential location and three alternatives with SAV with ride-sharing that the alternatives and scenarios are all the same as the above choice experiment

↓

Socio-demographic Characteristics

Individual:

- Gender, Age, Marital status, Occupation, Education level, Car license ownership, Scooter license ownership

Household:

- Household size, Number of children, Number of the worker, Income, Car ownership, Car license ownership, Scooter ownership, Scooter license ownership

Figure 3 Survey structure design

This target group of this survey is residents in the Taipei metropolitan area who is above age 15. Thus, the filter questions regarding age and city of residence are set up before the start of the main survey.

Regarding the survey structure shown in Figure 3. Firstly, the travel characteristics are investigated to obtain the current travel behaviors of recent respondents' most frequent trip purpose including attributes of travel time and travel cost that will be presented as variables of current alternative in the stated choice experiments. Besides, the perception toward sharing and autonomous mobility are asked to identify if people who heard of or interested in the sharing or autonomous are more likely to use SAV alternatives.

Secondly, the residential location characteristics are investigated to obtain the attributes of current cities and districts of residence and the most frequent trip destination, property type, and property cost that will also be presented as variables of current alternative in the stated choice experiment for residential location choice.

Thirdly, the stated choice experiments of mode choice and residential location choice will be presented. For the stated mode choice experiments, respondents are asked to choose one alternative among three alternatives, including the current mode, SAV without ride-sharing and SAV with ride-sharing totally in 4 scenarios with different attribute levels. For stated residential location experiments, two choice experiments that one is SAV without ride-sharing and SAV with ride-sharing are presented to respondents. In each choice experiment, respondents are asked to choose one alternative among four alternatives including the current alternative, not moving but shift to SAV, move farther from the most frequent trip destination, and move closer to the most frequent trip destination with SAVs. The detail of designing the stated choice experiments of mode and residential location choice will be elaborated in the next two sections.

At last, the socio-demographic characteristic in terms of individual and household level are investigated in order to have more insight into respondents' socio-demographic attributes.

3.1.2 Stated choice experiment design for mode choice

3.1.2.1 Alternatives and attributes

For designing the stated choice experiments for mode choice, the introduction of SAVs is firstly presented including the concepts of the unnecessity of car ownership, provision of ride-sharing, and door-to-door service in order to make respondents gain more understandings to this future transport mode.

Afterwards, three alternatives are designed including the current alternatives, SAV without ride-sharing, and SAV with ride-sharing with one other passenger in order to investigate whether the respondents will shift to SAV alternatives and examine the preference of choosing between using SAV alone and share SAV with another passenger. The number of passengers to share with is set to one in the SAV with ride-sharing alternative in order to make it distinguishable compare to SAV without ride-sharing with the travel cost is almost halved while travel time slightly increased by picking up and dropping down the other passenger.

For the selection of attributes, travel cost and travel time are selected based on the previous research that are significant attributes for the mode choice (Krueger et al., 2016; Haboucha et al., 2017; Winter et al., 2018; Yu 2019; Zhou et al., 2020). The travel time includes access time, egress time, waiting time, in-vehicle time, and travel cost include fuel cost and parking cost for private car and scooter, ticket fare cost for public transit modes and public bike. From the previous research, the waiting time is estimated to be the significant attribute to affect the acceptance of SAV (Krueger et al., 2016; Haboucha et al., 2017; Zhou et al., 2020). Therefore, the total travel cost, total travel time, and waiting time will finally be presented to respondents in the stated mode choice experiment. Table 10 shows how the attributes' value of the ten current modes is derived. Moreover, it is worth noting that the driver and passenger of private mode are counts together as single mode.

Table 10 Calculation of each attribute value of the current modes' alternative for stated mode choice experiment

	Mode	Total travel Cost	Total travel time	Waiting time
Private mode	Private Car (Driver)	In-vehicle travel time × Speed* × Fuel cost rate* (NTD/km) + Parking cost	Access + Egress + In-vehicle travel time	0
	Scooter (Driver)			
	Private Car (Passenger)	(1/1+number of passengers) × In-vehicle travel time × Speed* × Fuel cost rate* (NTD/km) + Parking cost		
	Scooter (Passenger)			
Public transit	Metro	Transit fare of Metro	Access + Egress + Waiting time + In-vehicle travel time	Waiting time
	Bus	Transit fare of Bus		
	Taxi	Taxi fare / number of passengers	Access + Waiting time + In-vehicle travel time	
Active mode	Bike	0 or Fare of public bike	In-vehicle travel time	0
	Walk	0	0	
Sharing mode	Car-sharing	Fare of car-sharing	Access + Egress + In-vehicle travel time	0
	Scooter-sharing	Fare of scooter-sharing		Waiting time
	Ride-sharing	Fare of car-sharing / number of passengers	Access + Waiting time + In-vehicle travel time	0

Note: Speed are is the reference value shown in Table 12, and Fuel cost rate of private car and scooter are 3 and 1 (NTD/km) respectively

Table 10 shows that the total travel cost of the two private modes is calculated by the sum of the fuel cost and parking cost. The parking cost is directly answered by respondents. In contrast, fuel cost is derived from trip distance consists of in-vehicle travel time multiply vehicle speed and multiply fuel cost fare which is 3 and 1 NTD/km for private car and scooter respectively (Lin et al., 2011). The amount of fuel cost is not asked in the survey because most of the people often not aware of their fuel cost for their single trip.

Regarding the three attributes of two SAV alternatives shown in Table 11, the values of attributes are all derived from the attributes' value of the current alternative. Regarding the total travel cost of both SAV alternatives, they are derived from 40 NTD base fare for the first kilometer, and the multiplication of SAV fare rate and trip distance for the following kilometers. Regarding the total travel time comprises of waiting time and in-vehicle time, the waiting time has two attribute levels that will be discussed in the next section. The in-vehicle travel time of SAVs are derived from the in-vehicle time of current mode multiply the ratio of the speed of current mode to the speed of SAV which is set as 30km/hour as same as the speed of the private motorized vehicle according to Burns (2013) and Krueger et al. (2016). Moreover, because the SAV with ride-sharing alternative will take longer time than SAV without ride-sharing for picking up and dropping off another passenger thus the in-vehicle time and waiting time are assumed to increase by 20% according to Fagnant & Kockelman (2016), and Wilson (2015).

Table 11 Calculation of each attribute value of two SAV alternatives for stated mode choice experiment

SAV alternatives	Total travel Cost	Total travel time	Waiting time
SAV without ride-sharing	40+(Current in-vehicle travel time ×Current speed-1)×SAV fare rate (4,8 NTD/km)	Waiting time + Current in-vehicle travel time ×Current Speed / 30	(5,10) minutes
SAV with ride-sharing	(1/2) × (40+1.2×In-vehicle travel time × Speed -1) ×SAV fare rate (4,8 NTD/km)	Waiting time + 1.2 × Current in-vehicle travel time × Current Speed / 30	1.2 × (5,10) minutes

Note: Total travel cost of SAV with ride-sharing is halved due to the share with another passenger

Furthermore, the average speed, cost, and average trip length of conventional transport modes and new mobility services such as a car- and ride-sharing in the Taipei metropolitan area shown in Table 12 are based on the research of Chang & Guo (2007) and information of Taiwan Railways Administration (2020), Taiwan High Speed Rail (2020), Uber Taiwan (2020), iRent (2020), and Zipcar (2020). The average speed can be referred to derive the fuel cost of private car and scooter, and total travel cost and total travel time of both SAV alternatives. The average travel cost per kilometer per trips and average trip length will be used as the reference for deriving attribute levels of each scenario in the next section. Besides, it is worth mentioning that the values did not be calibrated by inflation rate to represent the future context because respondents are assumed to use the current perception of cost to decide their choice.

Table 12 Characteristics of the current transport modes in the Taipei metropolitan area (Chang & Guo, 2007; Taiwan Railways Administration, 2020; Taiwan High Speed Rail, 2020; Uber Taiwan, 2020; iRent, 2020; Zipcar, 2020)

Mode	Average speed (km/hour)	Average travel cost per kilometer per trips (NTD/km/trip)	Average trip length (km)
Private Car	30	7.6	18.5
Scooter	30	2.8	8.4
Train	50	1.4	29.1
High-speed rail	110	4.4	36.4
Metro	34	2.4	7.7
Bus	23	1.8	7.9
Taxi	30	25 (70 NTD for first 1.25 km)	4.5
Car-sharing	30	3 (183 NTD for first 1 hour)	10
Ride-sharing	30	27.9 (110 NTD base fare)	10
Bike	12	0 or 0.8 (Public bike)	0.8
Walk	2	0	0.5

Note: The parking cost is not included in average travel cost per kilometer per trips of the private car.

Finally, the stated mode choice experiment will be presented as Table 13 shows. The value of attributes in each alternative will vary with the value that respondents' response in their current travel characteristics, namely, the attributes' value of the current alternative.

Table 13 Alternatives and attributes of the stated mode choice experiment

Attribute \ Alternative	Current Alternative	Alternative 1 SAV without ride-sharing	Alternative 2 SAV with ride-sharing
Total Travel cost	Directly from respondents and from Table 10	From Table 11	From Table 11
Total Travel time			
Waiting time			

3.1.2.2 Attribute levels

Attribute levels of SAVs are set in the stated mode choice experiments in order to distinguish the respondents' choice among different variation of attributes' value. Regarding the travel cost, the fare rate of two SAV alternatives including SAV without ride-sharing and SAV with ride-sharing is set to two levels: 4 and 8 (NTD/km) with the base fare of 40 NTD in the first 1 kilometer. Regarding waiting time, it is set to 5 and 10 minutes. Overall, there will be four combinations; thus, the full factorial design is applied since four choice sets are presumably in an acceptable range for respondents to finish. Therefore, four scenarios are set in this stated choice experiment with different attribute levels shown in Table 14.

Table 14 The attribute levels of stated mode choice experiment in each scenario

Scenario	SAV fare rate	Waiting time
Scenario 1	4 NTD/km	5 minutes
Scenario 2	8 NTD/km	5 minutes
Scenario 3	4 NTD/km	10 minutes
Scenario 4	8 NTD/km	10 minutes

Note: The waiting time in SAV with ride-sharing alternative will multiply 1.2

Regarding the attribute levels of travel cost, the reason for setting the attribute levels of SAV fare rate of 4 and 8 NTD per kilometer is because it is expected that the SAVs would have lower fare rate than the taxi and ride-sharing such as Uber. On the other hand, it is expected that the fare rate of the SAVs would be higher than public transit so that relatively less share of public transit is expected to shift to the SAVs than the shift from the private modes. Besides, the gap between the fare rate of SAV and private car is set within 4 NTD per kilometer referred to Table 12. Thus, it is more likely to observe the choice behavior between private car and SAVs in the reasonable price range. This condition is shown in Equation 1 and 2. Where TC_{Mode} is travel cost per kilometer (i.e., fare rate) of each mode, the unit is NTD per kilometer.

$$Max(TC_{Metro}, TC_{Bus}) < TC_{SAV} < Min(TC_{Taxi}, TC_{Ride-Sharing}) \quad (1)$$

$$|TC_{SAV} - TC_{Car}| < 4\ NTD/km \quad (2)$$

For setting the reasonable total travel cost of the SAVs, the total travel cost of the SAVs is set to be lower than the average total travel cost of a taxi and current ride-sharing services such as Uber, and higher than the average total travel cost of public transit. This condition is shown in Equation 3. Where TTC_{Mode} is the total travel cost of each mode, the unit is NTD which is travel cost per kilometer TC_{Mode} multiply average trip length D_{Mode}.

$$Max(TTC_{Metro}, TTC_{Bus}) < TTC_{SAV} < Min(TTC_{Taxi}, TTC_{Ride-Sharing}) \quad (3)$$

Besides, in order to avoid active mode users, who have relatively shorter trip length than private modes and public transit, shifting to SAV because of the drastically-reduced travel time with the lower fare, the base fare 40 NTD is set for the first 1 kilometer. It is set to be lower than the first 1 kilometer of the taxi, which is 56 NTD referred from Table 12. This condition is shown in Equation 4, where TTC_{SAV} is the total travel cost of the SAVs which is equivalent to 40 NTD plus travel cost per kilometer TC_{SAV} multiply trip length D_{SAV} minus 1 kilometer.

$$\begin{cases} TTC_{SAV} = 40 + TC_{SAV} \times (D_{SAV} - 1) & if\ D_{SAV} > 1 \\ TTC_{SAV} = 40 & if\ D_{SAV} \leq 1 \end{cases} \quad (4)$$

Finally, the relational graph of total cost and trip length of each transport mode referred from Table 12, including all modes above in comparison to two SAV alternatives is demonstrated in Figure 4 and 5.

In Figure 4 which presents the scenario of SAV fare rate of 4 NTD/km shows that the total travel cost of SAV without ride-sharing will be lower than the cost of the private car when the distance is farther than 10 km, which means that most of the private car users are expected to shift to SAV without ride-sharing mainly because of the reduction in travel cost with similar travel time. Besides, though the cost of two public transit modes is less than both SAV alternatives, the travel time of public transit modes are expected to be longer than SAVs thus it is unpredictable that if the public transit users will shift to both SAV alternatives. It is also worth noting that the total travel cost of SAV with ride-sharing will be close to the cost of the scooter at the distance of 18 km, which means that long-distance users of scooter might be expected to shift to SAV with ride-sharing mainly because of the reduction in access and egress time with similar trave cost.

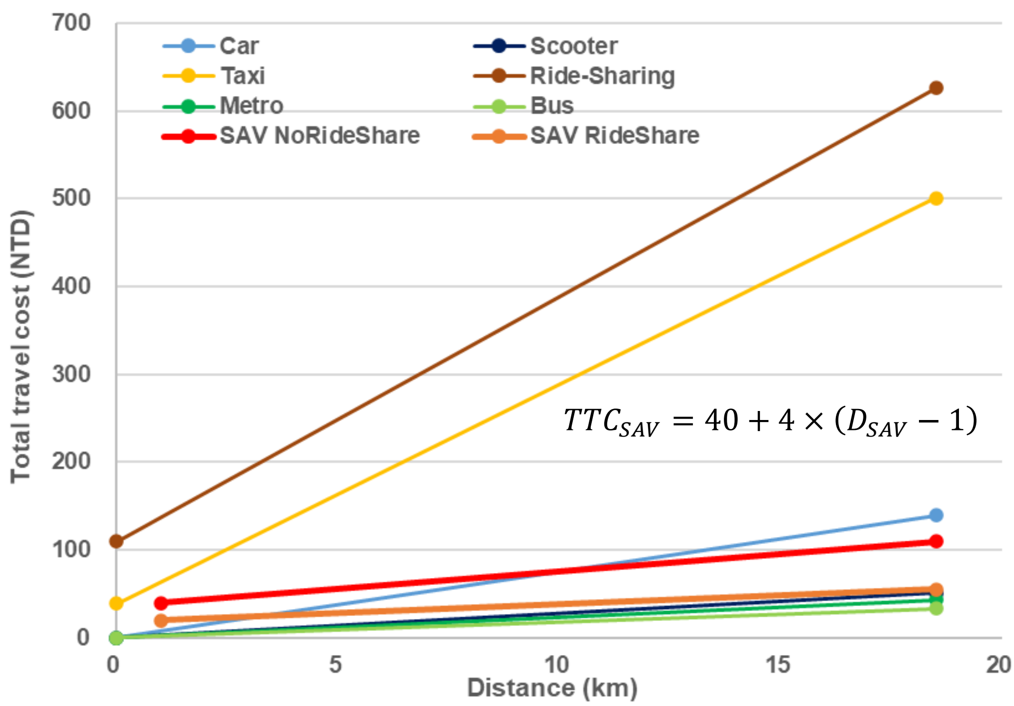

Figure 4 Referred total travel cost with SAV fare rate of 4 NTD/km

In Figure 5 which presents the scenario of SAV fare rate of 8 NTD/km shows that the total travel cost of SAV without ride-sharing will have fixed gap of approximate 40 NTD with the private car, which can examine if the users of private car are likely to shift to SAV without ride-sharing because of the liberation of their in-vehicle time to do other activities or affairs. It is also worth noting that the total travel cost of SAV with ride-sharing will be lower than the cost of the private car while the distance is at approximately 5 km, which means that short-distance users of the private car are expected to shift to SAV with ride-sharing because of the reduction in travel cost with similar travel time.

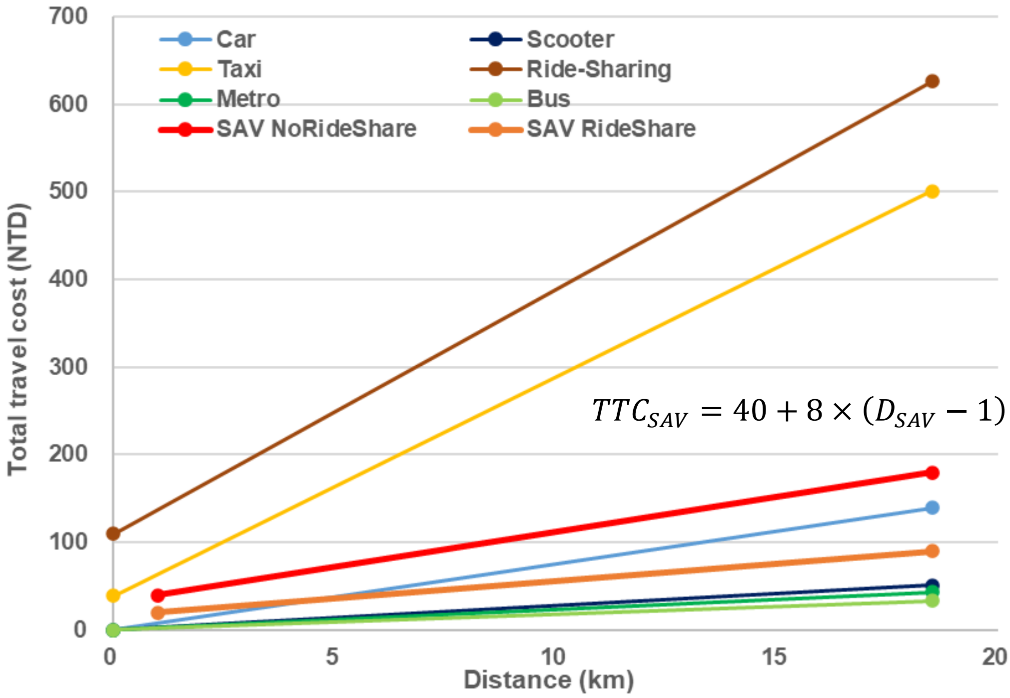

Figure 5 Referred total travel cost with SAV fare rate of 8 NTD/km

Regarding the attribute levels of waiting time, it is set to 2 levels: 5 and 10 minutes by referencing Fagnant & Kockelman (2016), Krueger et al. (2016), Chen & Kockelman, (2016), and Winter et al. (2018) in order to have noticeable variation. Moreover, the levels of waiting time of SAV with ride-sharing is 6 and 12 minutes which are 20% higher than SAV without ride-sharing according to Fagnant & Kockelman (2016), and Wilson (2015).

3.1.3 Stated choice experiment design for residential location choice

3.1.3.1 Alternatives and attributes

For designing the stated choice experiments for residential location choice, there are two choice experiments that one is to choose a residential location with the introduction of SAV without ride-sharing, and the other is with the introduction of SAV with ride-sharing. The reason for designing two experiments is because to distinguish the similarities and differences of residential location choice between both SAV modes, and also to keep the limited number of alternatives in each choice set in order to make respondents easier to absorb the information. In each stated choice experiment, four alternatives are designed including the current alternative, not moving but shift to SAVs, move farther from the most frequent trip destination with SAVs and move closer to the most frequent trip destination with SAVs.

For the selection of attributes, property cost, single travel time, and monthly travel cost are selected based on previous research Bansal et al. (2016), Zhang & Guhathakurta (2018), Carrese et al. (2019), and Gelauff et al. (2019). The property cost is classified into housing cost for those who own their property, and monthly rent for those who rent the property. The housing cost and monthly rent demonstrating to respondents that are varied according to their residential location and the most frequent trip destination based on their current housing price and monthly rent in each city and district. The changes in property cost with different relation of residential location and the most frequent trip destination is shown in Table 15. The cost of housing and monthly rent is set to decrease when respondents choose to move farther from their destination of the most frequent trip. On the other hand, the cost of housing and monthly rent is set to increase if respondents choose to move closer to their destination of the most frequent trip. The estimated percentage of housing and rent cost changes is based on the property price data between 2018 and 2020 of several housing agencies (Sinyi, 2020; CBCT,2020; HouseFun,2020).

Table 15 Changes in property cost with different relation of residential location and the most frequent trip destination

Property cost	Relation of residential location and the most frequent trip destination	Alternative of moving farther from / closer to the most frequent trip destination
Housing cost	In different cities	- 50% / + 100%
	In same city but different district	- / + 20%
	In same city and same district	- / + 10%
Monthly rent	In different cities	- 50% / + 100%
	In same city but different district	- / + 20%
	In same city and same district	- / + 10%

Note: The alternatives of current and not moving but shift to SAV has no change in property cost.

For the attribute of single travel time, it is assumed that people take the single travel time more into account than accumulated travel time (e.g., Monthly travel time) when deciding the alternative of their residential location since the single travel time are the more intuitive way for people to consider for their mobility pattern. The single travel time is also varied according to the cities and districts of residential location and the most frequent trip destination. The changes in single travel time shown in Table 16 are derived from the current trip distance that converts from respondents' current travel time, and speed of mode referred to Table 12.

Table 16 Changes in single travel time with different relation of residential location and the most frequent trip destination

Single travel time	Relation of residential location and the most frequent trip destination	Alternative of moving farther from / closer to the most frequent trip destination
All modes	In different cities	+ / - 75%
	In same city but different district	+ / - 50%
	In same city and same district	+ / - 25%

Note: The alternatives of current and not moving but shift to SAV has no change in property cost.

For the attribute of monthly travel cost. In contrast to the single travel time, it is assumed that people take the monthly travel cost more into account than travel cost of the single trip when deciding the alternative of their residential location since people tend to consider the monetary cost in a long-term way. The monthly travel cost is calculated by multiplying attributes including travel cost of a single trip, trip frequency (round trips/week) , 2 (trips/round trip), and 4 (weeks/month) that shown in Equation 5, where $MTTC$ is monthly travel cost, TTC is single total trip cost, and $TripFreq$ is trip frequency. Both values of TTC and $TripFreq$ are directly obtained from the survey.

$$MTTC = TTC \times TripFreq \times 2 \times 4 \tag{5}$$

The monthly travel cost is also varied according to the cities and districts of residential location and the most frequent trip destination. The percentage changes in monthly travel cost shown in Table 17 derived from percentage changes in single travel time shown in Table 16, and estimated cost based on fuel cost of motorized modes, the fare of public transit, and active modes. The costs of the motorized modes are the most distance-sensitive, while the costs of the active modes are the least sensitive to distance.

Table 17 Change in monthly travel cost with different relation of residential location and the most frequent trip destination

Monthly travel cost	Relation of residential location and the most frequent trip destination	Alternative of moving farther from / closer to the most frequent trip destination
Motorized modes	In different cities	+ / - 75%
	In same city but different district	+ / - 50%
	In same city and same district	+ / - 25%
Public Transit	In different cities	+ / - 50%
	In same city but different district	+ / - 25%
	In same city and same district	+ / - 0%
Active modes	In different cities	+ / - 25%
	In same city but different district	+ / - 0%
	In same city and same district	+ / - 0%

To sum up, regarding all attributes of the stated residential location choice experiments, this research assumes that the farther the respondents move away from their most frequent trip destination, the less property cost, the higher monthly travel cost, and the longer travel time they will have; The closer the respondents move to their most frequent trip destination, the more property cost, the less monthly travel cost, and the less travel time they will have. Besides, regarding the relation of residential location and the most frequent trip destination, this research assumes that both locations above are in the same city and district has the least changes in the magnitude of all three attributes since it is assumed that this group of people are willing to move in the smallest relocation range. In contrast, if aforementioned locations are in different cities, this group of people are willing to move in the most extensive relocation range.

Finally, the stated residential location choice experiments will be presented as Table 18 shows. The value of attributes in each alternative will vary with the value that respondents' answers in their current residential characteristics, namely, the attributes' value of the current alternative.

Table 18 Alternatives and attributes of stated residential location choice experiments

Alternative / Attribute	Current Alternative	Alternative 1 Not moving but shift to SAVs	Alternative 2 Move farther from the most frequent trip destination with SAVs	Alternative 3 Move closer to the most frequent trip destination with SAVs
Property cost	Directly from respondents	No change	From Table 15	
Single travel time		From Table 11	From Table 16	
Monthly travel cost			From Table 17	

Note: SAVs includes SAV without and with ride-sharing in each experiment

3.1.3.2 Attribute levels

For setting the attribute levels of SAVs in the stated residential location choice experiments, the same attribute levels in the stated mode choice experiment are used. The fare rate of SAVs is set to two levels: 4 and 8 (NTD/km) with the base fare of 40 NTD in the first 1 kilometer, and the waiting time is set to 5 and 10 minutes. Since there are two stated choice experiments for residential location choice with SAV without and with ride-sharing, the fractional factorial design is applied that there are two scenarios for each SAV alternative with the combination of two extreme attribute levels. Therefore, there will be more considerable variations in the attributes of single travel time and monthly travel cost. Overall, two scenarios in both SAV alternatives are set in this stated residential location experiments with different attribute levels shown in Table 19.

Table 19 The attribute levels of stated residential location choice experiments in each scenario

SAV alternatives	Scenario	SAV fare rate	Waiting time
SAV without ride-sharing	Scenario 1	4 NTD/km	5 minutes
	Scenario 2	8 NTD/km	10 minutes
SAV with ride-sharing	Scenario 1	4 NTD/km	1.2×5 minutes
	Scenario 2	8 NTD/km	1.2×10 minutes

Note: The waiting time in SAV with ride-sharing multiplies 1.2, according to Fagnant & Kockelman (2016), and Wilson (2015).

3.1.4 Pilot and main survey

After the design of the survey structure and stated choice experiments, the pilot survey was conducted in order to gain feedback regarding the legibility and understandability of the survey content from the respondents. Fifteen respondents participated in the pilot survey, including respondents major in transportation expertise and people with other expertise. Most of the participant took the survey over 20 minutes and revealed that the survey was too long. Thus questions regarding the user perception of their current transport mode are removed. It is also suggested that the introduction of the SAV and the stated choice experiments can be streamlined to avoid too much detailed description and derivation of attributes. At last, some terms such as trip, access and egress time, and in- and out-of-vehicle time are modified more understandably for respondents to understand the meaning of these terms quickly.

After the pilot survey was conducted, the main survey was officially started on 8th August 2020 for the one-month data collection period to 8th September 2020. The survey was distributed online mainly via e-mail and social media to the author’s connections in every age group and further distributed by the networks of those connections. Besides, the survey was also distributed to chiefs of neighborhood, public and private organizations in every district of the city in order to get more respondents from out of the author’s network and obtain data uniformly in each district and city. Fourteen small prizes are provided for selected respondents in order to stimulate the willingness to fill the survey. After finishing collecting the data, the survey data analysis was conducted that will be described in Chapter 4.

3.2 Discrete choice model estimation

After the data collection by stated preference (SP) survey was finished. The discrete choice analysis was conducted in order to build the mode choice and residential location model. Firstly, the correlation of variables from the SP survey is tested. Secondly, the chosen variables are used to build models.

3.2.1 Correlation tests

The correlation tests are the statistical test that estimates the statistical relationship between two continuous variables. Therefore, the variables obtained from the survey were tested in order to select the variables that are not correlated with each other. Pearson's correlation test is applied in this research. Since only the continuous can be tested, the categorical variables were all changed to dummy variables to test with numerical variables. Pearson's correlation coefficient, which larger than 0.6 and less than -0.6 are considered the two variables are highly correlated; thus, one of them will be removed in this research.

3.2.2 Discrete choice model

After the correlation test for the selection of the variables, the mode choice and residential location choice model were estimated with conventional logit model by using Biogeme package under Python programming environment which is designed to estimate the parameters of discrete choice models by using maximum likelihood estimation (Bierlaire, 2020). Biogeme has embedded the variable of mode availability that can identify which modes are available for each respondent and then only estimate the parameters of available modes. For the survey of this research, some modes like metro are not available in some districts, and other modelling tools did not embed this function. Thus Biogeme becomes the priority to estimate the models.

Regarding the discrete choice model, the multinomial logit (MNL) model is used for all mode choice and residential location choice models. The MNL model is based on the assumption of independence of irrelevant alternatives (IIA), which means that all alternatives are assumed to be independent of each other. Therefore, the probability of each alternative being chosen is shown in Equation 6. Where C is the choice set of mode and residential location alternatives, U_i is the utility of alternative i, U_j is the utility of all alternatives. The utility maximization theory will be applied so that the alternative with the highest utility will be selected as respondents‘ choice.

$$P_i = \frac{e^{U_i}}{\sum_{i \in C} e^{U_j}} \tag{6}$$

For the utility, it consists of an observed component that can be perceived with some attributes and residual unobserved component, which cannot be elaborated with observed data. The component of the utility is shown in Equation 7. Where U_{ni} is the total utility of decision-maker n for alternative i. V_{ni} and ε_{ni} are the observed component and the residual unobserved component of the decision-maker n for alternative i respectively.

$$U_{ni} = V_{ni} + \varepsilon_{ni} \tag{7}$$

Therefore, this research will do further investigation into the observed component of utility (i.e., V_{ni}). The Equation 8 shows the generally observed utility function that is consists of alternative-specific constant ASC, variables X, Y, etc., and coefficient β, which can be generic or alternative-specific depends on the variable, for the decision-maker n for alternative i. The coefficients of variables are estimated by maximizing the models‘ log-likelihood.

$$V_{ni} = ASC_i + \beta_{i,x} X_i + \beta_{i,y} Y_i + \cdots \tag{8}$$

For the utility function after the model specification of each alternative, it will be described in detail in Chapter 5 for the model estimation.

3.3 Case study

After the model estimation, there are two mode choice models and two residential location choice models to be applied to simulate the potential modal shift and residential location choice in the Taipei metropolitan area for the case study.

For the mode choice models, the RP-SP combined model which combines all alternatives of currently available modes and two SAV alternatives in one choice set is developed in order to explore the potential modal shift in the SAV-prevalent era. On the other hand, the SP model which consists of only the respondents' current mode in use and two SAV alternatives in one choice set in order to explore the extent of modal shift from each mode to each SAV alternative. Moreover, both survey data in this research and national household travel survey data from Taiwan Ministry of Transportation (2016) will be used to apply to the models in order to have more insight on what is the outcome of the modal split with two different datasets and how to process national household travel survey data to get more precise and closer modal split to the one simulated with survey data. Table 20 shows the types, alternatives, the expected finding of each mode choice model, and data to be simulated.

Table 20 Elaboration of two mode choice models and data to be simulated

Model type	Simulated data	Alternatives	Expected finding
RP-SP combined model	• Survey in this research • National household travel survey	• 8 current available modes • 2 SAV modes	Modal split in SAV-prevalent era
SP model		• 1 current mode in use • 2 SAV modes	Mode shift from each mode to each SAV alternative

Note: Some currently available modes are combined due to the low sample sizes

For the residential location choice models, there are two models that one is the relocation change with the introduction of SAV without ride-sharing, and the other is relocation change with the introduction of SAV with ride-sharing. The SP models which consist of respondents' current residential location and mode, and three relocation alternatives including not moving, moving farther from, and closer to the most frequent trip destination with SAVs are applied to the survey data of this research. Therefore, the percentage of relocation behavior with each SAV alternative will be identified. Furthermore, the relocation changes in each mode users and city will be simulated in order to identify the potential relocation trend in each mode and city with each SAV alternative. Table 21 shows the types, alternatives, the expected finding of residential location choice model, and data to be simulated.

Table 21 Elaboration of two residential location choice models and data to be simulated

Model type	Simulated Data	Alternatives	Expected finding
SP model with SAV without ride-sharing	• Survey in this research	• 1 current residential location and current mode in use • 3 Relocation alternatives shifting to SAVs	Changes in relocation distribution in the entire study area, each mode users and each city
SP model with SAV with ride-sharing			

Chapter 4. Survey Data Analysis

In this chapter, the survey data will be analyzed to have more insights into the mode choice and residential location choice behavior in terms of different travel characteristics, residential characteristics, and socio-demographic characteristics, in order to have a better understanding in model estimation in chapter 5. Firstly, the descriptive analysis, including the deriving weight of survey data and description of the travel characteristics, residential characteristics, and social demographic characteristics of survey data, will be elaborated. Secondly, the attitude toward SAVs and the result of stated choice experiments of mode choice and residential location choice in each scenario will be described.

4.1 Descriptive analysis

4.1.1 Sample description and socio-demographic characteristics

There are 613 responses from the survey after a one-month data collection period. After withdrawing unreasonable and inconsistent responses, 482 responses remain to be valid data. The distribution of sample based on six age groups, gender, and four cities of the Taipei metropolitan area are shown in Table 22.

Table 22 Population distribution of sample data in terms of cities and gender

Age	Taipei	New Taipei	Keelung	Taoyuan	Female	Male
15 - Under 20	3	5	0	1	5	4
20 - Under 30	87	59	4	17	85	82
30 - Under 40	28	26	2	18	38	36
40 - Under 50	33	22	2	13	33	37
50 - Under 60	55	30	1	14	53	47
60 and above	40	18	1	3	25	37
Total	**246**	**160**	**10**	**66**	**239**	**243**
		482			**482**	

The sample data will be compared with Taiwan census data collected before the end of July 2020 (Taiwan Ministry of Interior, 2020) to apply the weights, i.e., expansion factors, in order to ensure the survey data can represent the realistic population distribution in the Taipei metropolitan area. The weights are initially planned to be applied based on six age groups and the four cities in the Taipei metropolitan area. However, due to the lack of the sample size in Keelung City that is insufficient to represent the travel behavior in that city, weights are applied based on six age groups and gender. Besides, weights are calculated based on the percentage of population by age groups and gender instead of population number since all weights will exceed 500 which are not applicable due to a large population in the Taipei metropolitan area. The comparison of survey data and census data with weights is shown in Table 23.

Table 23 Comparison of survey data and census data (Taiwan Ministry of Interior, 2020)

Age	Survey data		Census data		Weights	
	Female	Male	Female	Male	Female	Male
15 - Under 20	1%	0.8%	2.7%	2.9%	6.48	8.86
20 - Under 30	17.6%	17%	7.1%	7.5%	1	1.11
30 - Under 40	7.9%	7.5%	8.8%	8.6%	2.8	2.87
40 - Under 50	6.8%	7.7%	9.7%	9%	3.54	2.9
50 - Under 60	11%	9.8%	9.3%	8.3%	2.12	2.14
60 and above	5.2%	7.7%	14.2%	11.8%	6.83	3.85
Total	**49.6%**	**50.4%**	**51.8%**	**48.2%**		
	100%		**100%**			

4.1.2 Travel characteristics

After the survey data is applied with weights in order to represent the realistic population distribution by age groups and gender, the most frequent trip purposes, mode share, travel time, and travel cost will be explored.

Regarding the respondents' most frequent trip purposes shown in Table 24, over 70% of the respondents make work trips and compare to the national household travel survey data, percentage of the work trip is overrepresented approximately 30%, and the school trip is almost identical. In contrast, the percentage of other trips are underrepresented. Therefore, this research will mostly reveal the mode choice and residential choice behavior of the working population.

Table 24 The most frequent trip purposes with weighted survey data and national travel survey data (Taiwan Ministry of Transportation, 2016)

Trip purpose	Trips (%) Survey data	Trips (%) HH travel data
Work	74.1%	45%
School	9.3%	8%
Leisure	7.4%	14%
Shopping	4.6%	13%
Other	1.8%	-
Religion	1.3%	-
Personal visiting	1.0%	14%
Errand	0.4%	5%

Regarding the modal split that the respondents using for their most frequent trip shown in Table 25. Compare to the national household travel survey data, the mode share of private car and metro are overrepresented for approximately 17% and 14% respectively, the mode share of the train, taxi, bus, and bike are almost identical within 3% difference. In comparison, the scooter and walk are underrepresented for almost 10% and 7% respectively. Therefore, the mode choice model will be calibrated to the modal split of the national travel survey's observation later on in the model estimation process. Besides, since the mode of the train and high-speed rail has low sample sizes and both of them has similarity as long-distance modes and relatively high speed. Thus both modes are classified as a train. Similarly, taxi and ride-sharing are classified as a taxi since there is only one respondent use ride-sharing for the most frequent trip and both modes have a similar service pattern.

Table 25 Modal split the most frequent trip with weighted survey data and national travel survey data (Taiwan Ministry of Transportation, 2016)

Mode	Trips (%) Survey data	Trips (%) HH travel data
Private car	34.6%	18%
Scooter	16.7%	35%
Train	1.7%	2.50%
Taxi	1%	4%
Metro	26.1%	12%
Bus	13.4%	14%
Bike	3.1%	3%
Walk	3.4%	10%

Regarding travel time, which is composed of out-of-vehicle time, waiting time, and in-vehicle time shown in Figure 6. After weighting the survey data, the out-of-vehicle time consists of access and egress time, and approximately 85% of the out-of-vehicle time are within 20 minutes. For the waiting time is nearly all respondents are within 10 minutes, and for the in-vehicle time, almost 80% are within 30 minutes.

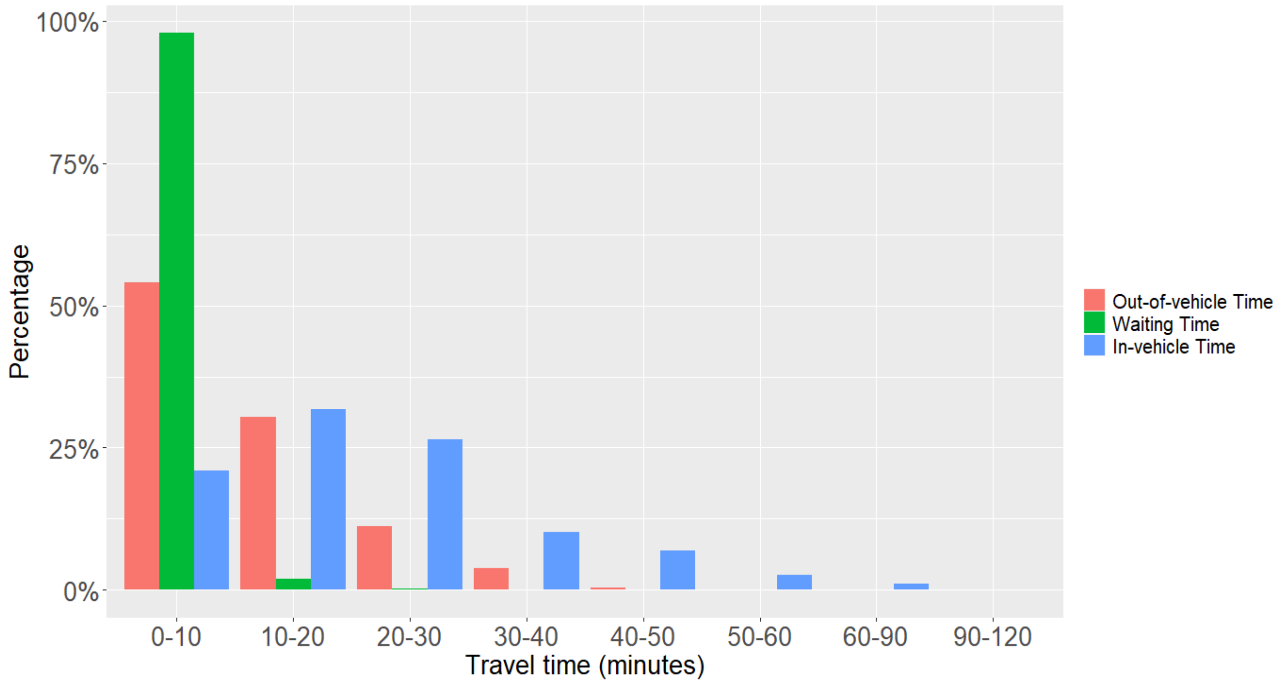

Figure 6 Distribution of three segments of travel time

For the transport modes with total travel time comprising out-of-vehicle time, waiting time, and in-vehicle time shown in Figure 7. After weighting the survey data, private modes including private car and scooter are concentrated in the range of 10-40 minutes, public transit including metro, bus, train, and taxi are almost evenly distributed from 20 to 90 minutes, while active mode including walking and cycling are mostly concentrated within 30 minutes. Overall, the total travel time of public transit users spends more time than private modes; it is most likely due to the longer out-of-vehicle time and waiting time. Moreover, active mode users spend less time than the users of the other two modes which they used to travel a relatively short distance.

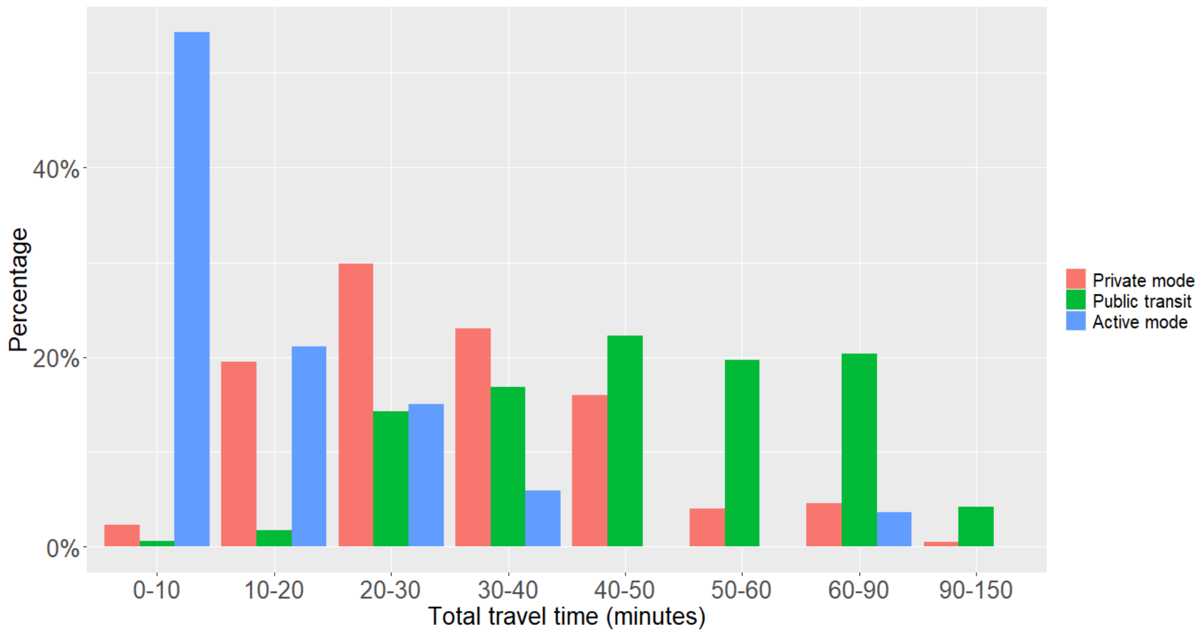

Figure 7 Distribution of total travel time by types of mode

For the travel cost, the fare for public transit, and fuel cost and parking cost for private motorized modes are shown in Figure 8. After weighting the survey data, almost 80% of the travel cost are within 50 NTD.

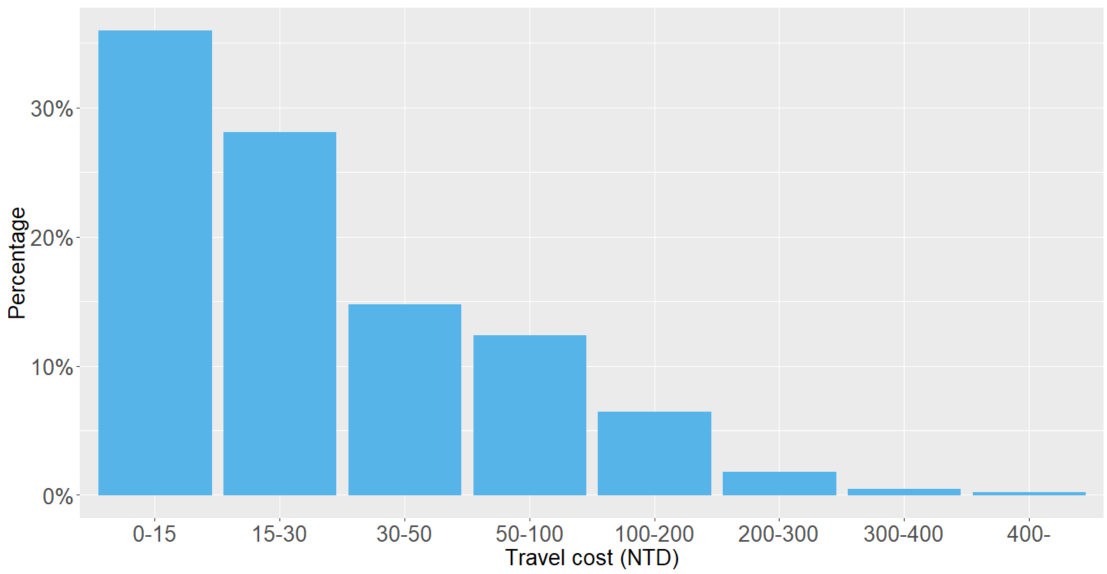

Figure 8 Distribution of travel cost

For the transport modes with travel cost shown in Figure 9. After weighting the survey data, nearly half of the private mode users spent less than 15 NTD because most of the scooter users do not spend any parking cost, and the fuel cost of the scooter is also relatively low. For those spend from 50 to 200 NTD are mostly car user because of the higher fuel cost and parking cost than the scooter. For public transit users, half of the public transit users spend less than 30 NTD which are mainly users of metro and bus, as for the users that spend over 50 NTD are mostly long-distance trains and taxi users. Most of the active mode users spend less than 15 NTD because of the relatively low price for public bikes and costless by using their bike and walking.

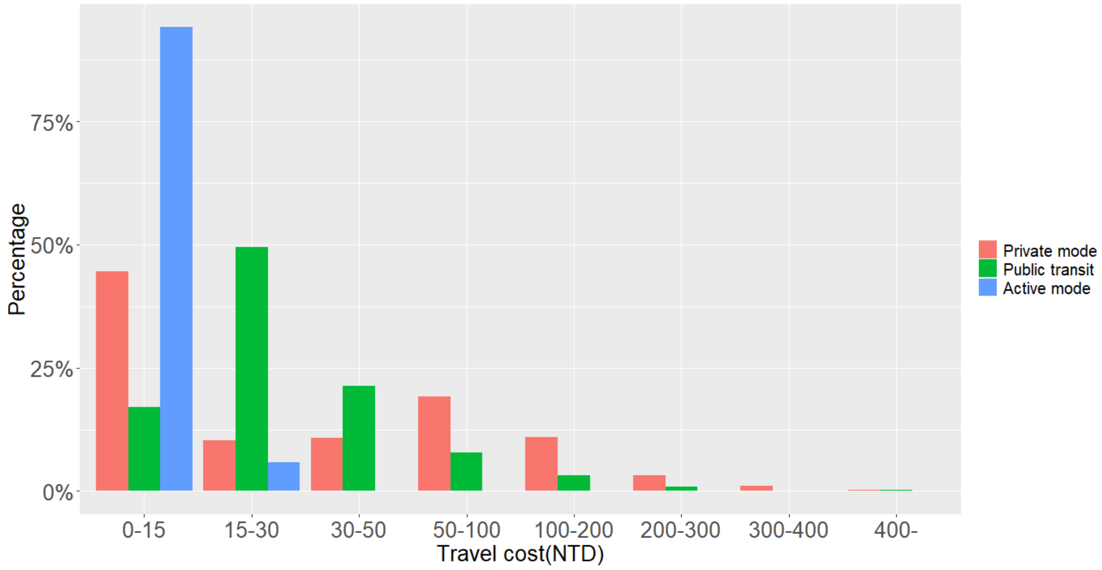

Figure 9 Distribution of travel cost by modes

4.1.3 Residential characteristics

The residential characteristics of this survey including the respondents' residential location, respondents' most frequent trip destination, property type, property cost including house price and monthly rent, and reasons that affect the choice of the residential location will be explored. Besides, it is worth noting that there are 460 responses were valid since 22 out of 482 responses filled unreasonable trip frequency that will miscalculate the attribute of monthly travel cost in residential location choice experiments.

Firstly, the population distribution of residential location and the most frequent trip destination with weighted survey data are shown in Figure 10 and 11. For the residential location distribution of this survey shown in Figure 10, the respondents of this survey are mainly live in Taipei City, where three districts exceed 5% of the total population. Five districts in New Taipei City close to the west side of Taipei City where are densely populated districts have 2.5 - 5% of the total population. Besides, there are also two districts, including the densely populated district in Taoyuan City have 2.5 - 5% of the total population. Overall the distribution of the residential location is in reasonable trend. However, residents in Taipei City are slightly over-represented since New Taipei City has more population than Taipei City, and residents in Keelung City is under-represented with low sample size.

For the most frequent trip destination of residents shown in Figure 11, the respondents of this survey are travel frequently mainly to Taipei City, where five districts exceed 5% of the total population. This trend indicates that Taipei City is still the central city that many activities take place. In New Taipei City, the population are almost evenly distributed around Taipei City with up to 2.5% of the total population. Besides, one district in Taoyuan City, where the airport located has almost 10% of the total population since quite many of respondents are working in the aviation industry. Overall, the distribution of the most frequent trip destination is in reasonable trend.

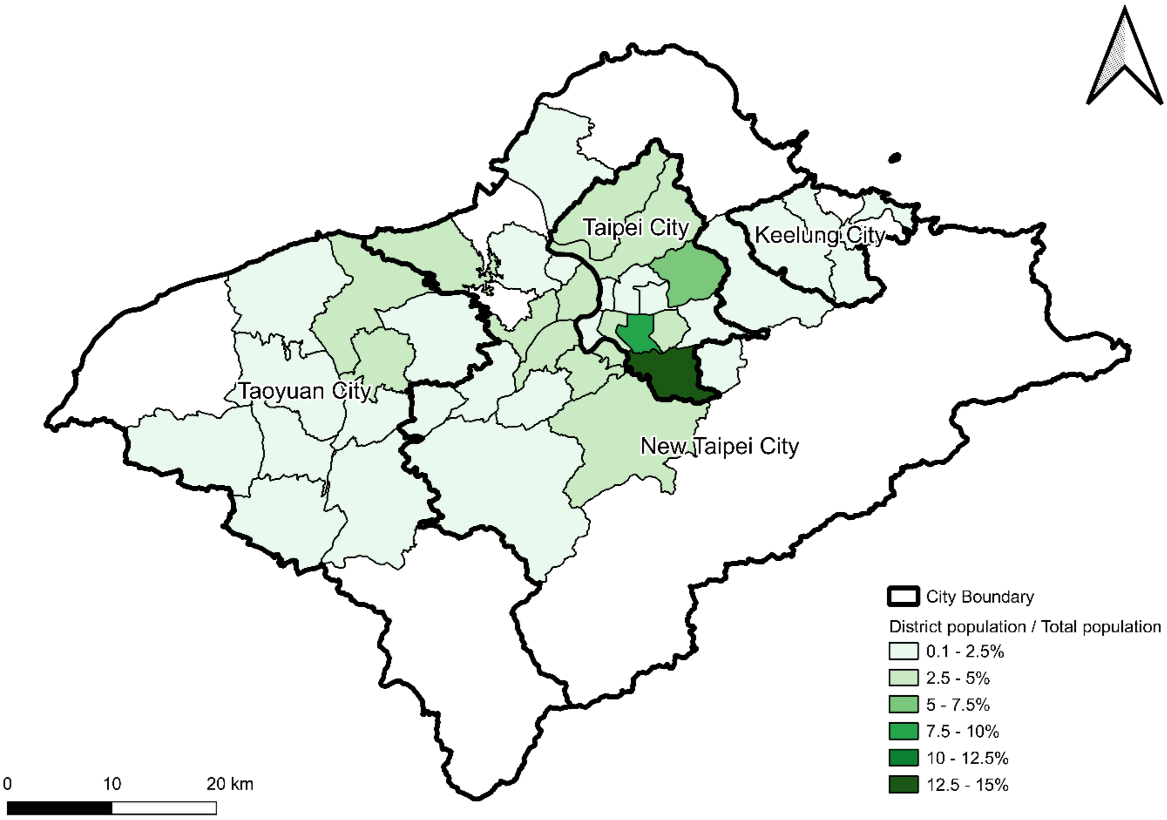

Figure 10 Population distribution of residential location

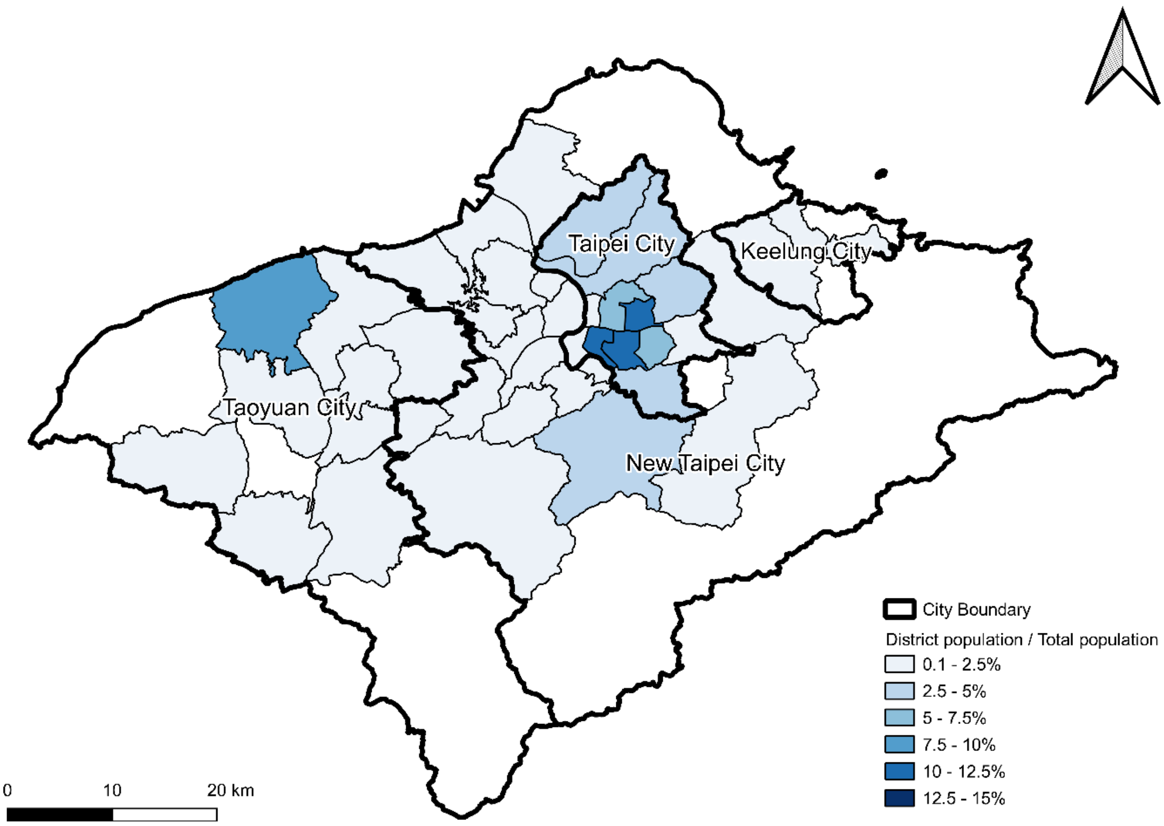

Figure 11 Population distribution of the most frequent trip destination

Secondly, regarding the distribution of the property type and property cost in this survey, there are 80% of respondents live in their property, and 20% live in rental property. Among the people live in their property shown in Figure 12, over 90% of the price are within 30 million NTD which is reasonable that most of the house price in the Taipei metropolitan area are not exceed 30 million. For the monthly rent for the residents of rental property shown in Figure 13, 95% of the monthly rent are within 30,000, which is also the reasonable price.

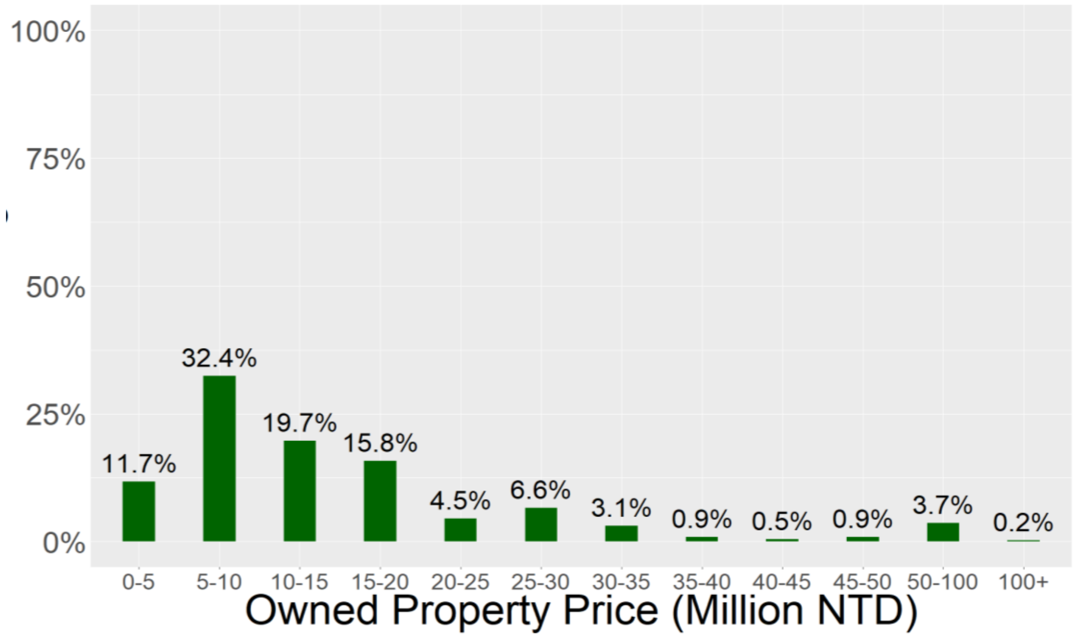

Figure 12 Owned property price of weighted survey data

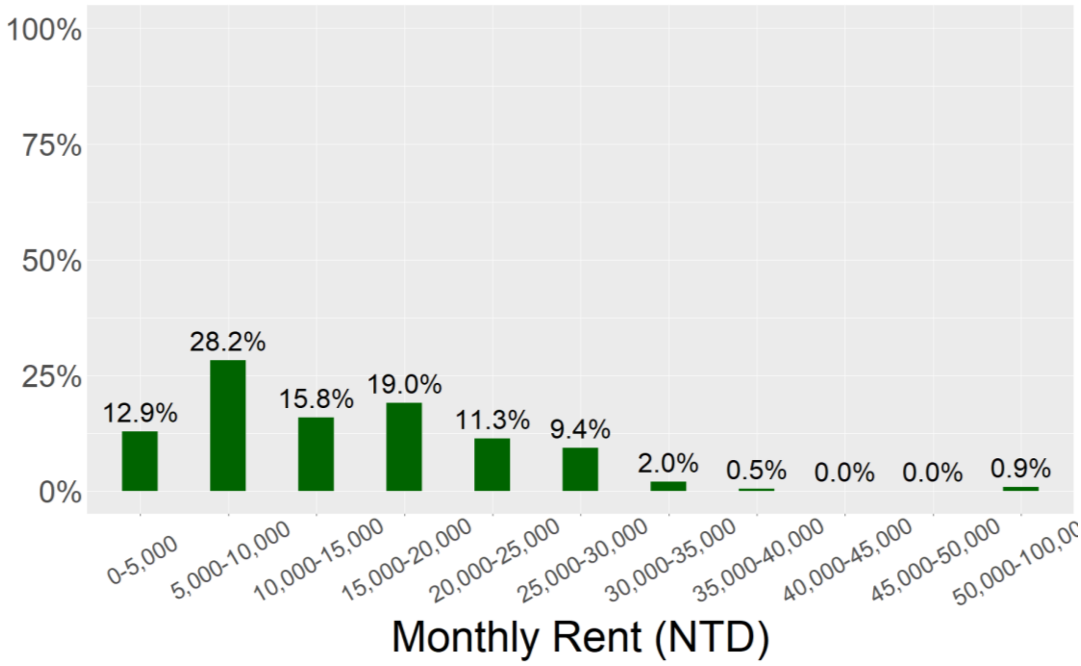

Figure 13 Monthly rent of weighted survey data

At last, regarding the reasons that affect the residential location choice, there are five most expected chosen reasons are listed in this survey to respondents who will rate each reason from very unrelated (i.e., 1) to significantly related (i.e., 5) with 5-point Likert scales shown in Figure 14. Over 50% of respondents consider all factors except the factor of proximity to family or relatives are related to their residential location choice (i.e., 4 - 5). Among these five factors, the cost of the property is the most influential factor, and the proximity to family or relatives is the least influential factor. This information is intended to be included in the residential location choice model in this study. However, there is no other similar data related to the factor that affect their residential location choice available. Thus, the information regarding this topic will only present in this subsection.

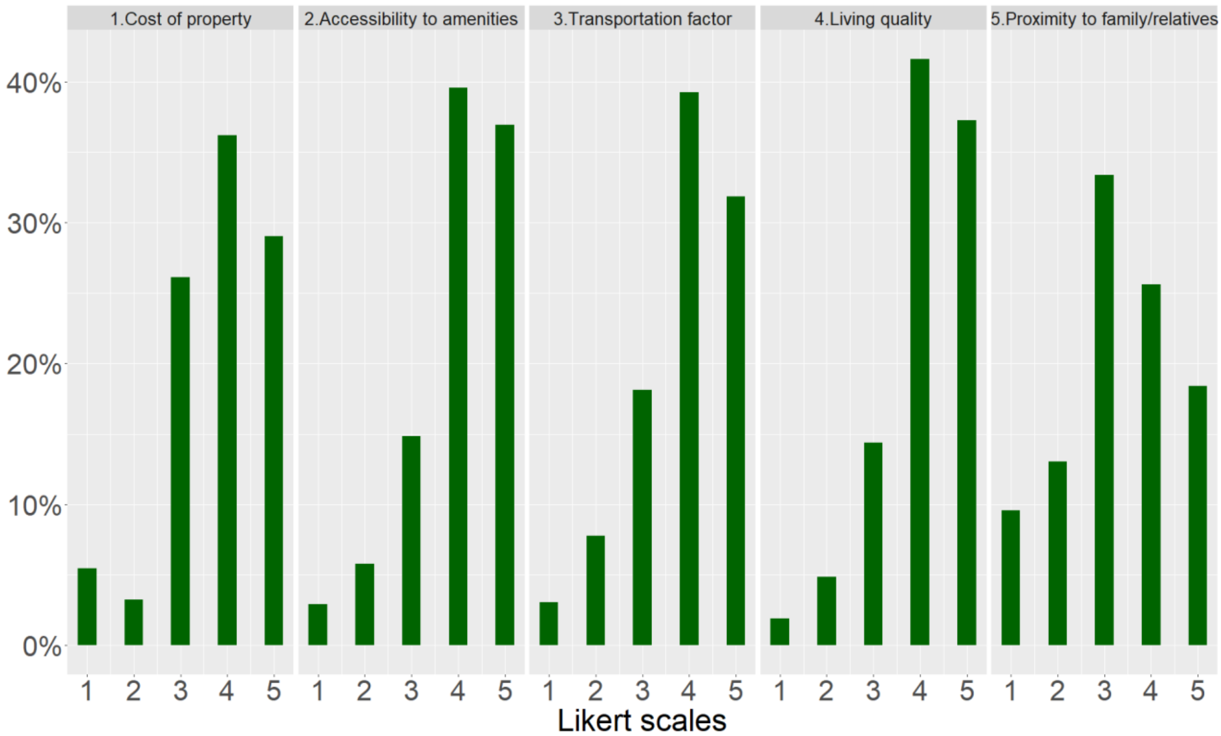

Figure 14 Reasons that affect the residential location choice

4.1.4 Socio-demographic characteristics

Finally, the socio-demographic characteristics including household size, household income, education level, household car ownership, and household scooter ownership will be described with the weighted survey data shown in Figure 15 to 19.

Firstly, the household size in Figure 15 is uniformly distributed, with almost 80% of the household has 2 to 4 persons. Secondly, the household income in Figure 16 is almost evenly distributed from 40,000 to 300,000 NTD, which is a reasonable income range for the household in the Taipei metropolitan area. Thirdly, the education level in Figure 17 shows that over 90% of the respondents have at least a university degree that is also the phenomenon that Taiwan has a very high university entrance rate. A last, for the household car and scooter ownership in Figure 18 and 19, over 75% of respondents have their car, and over 60% of respondents have their scooter.

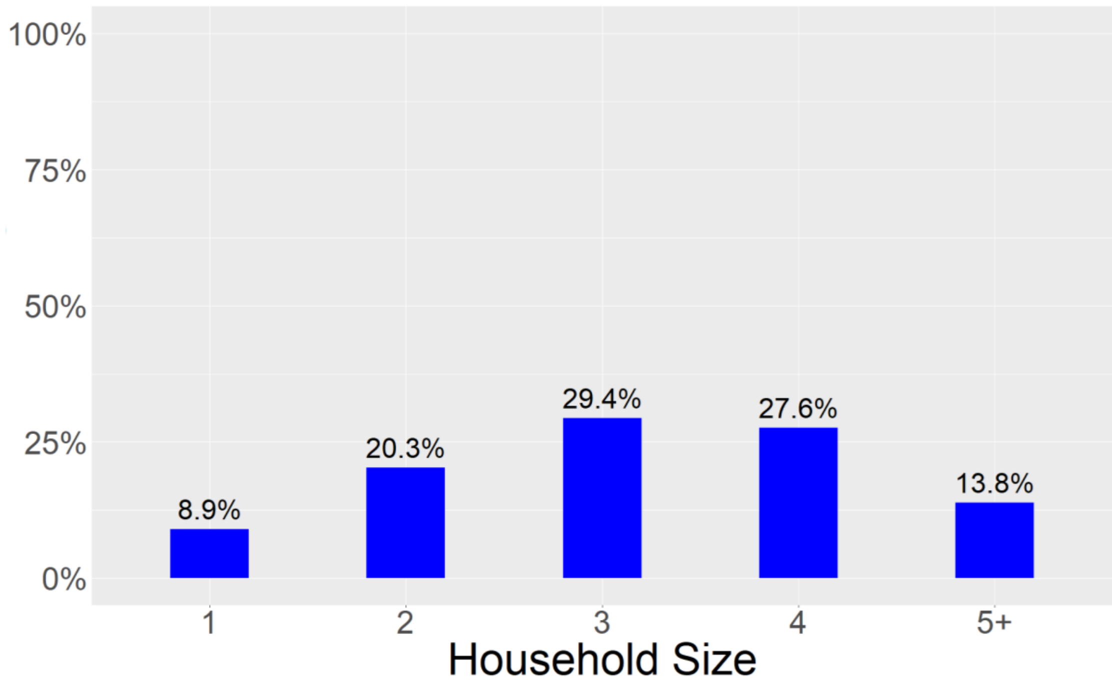

Figure 15 Household size of weighted survey data

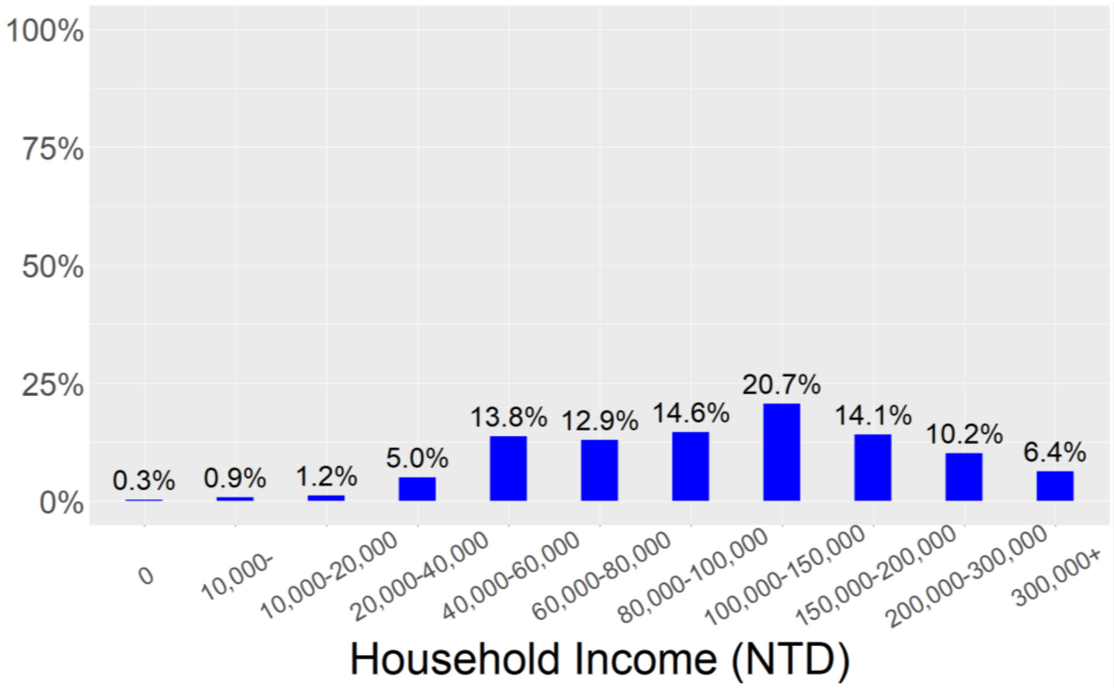

Figure 16 Monthly household income of weighted survey data

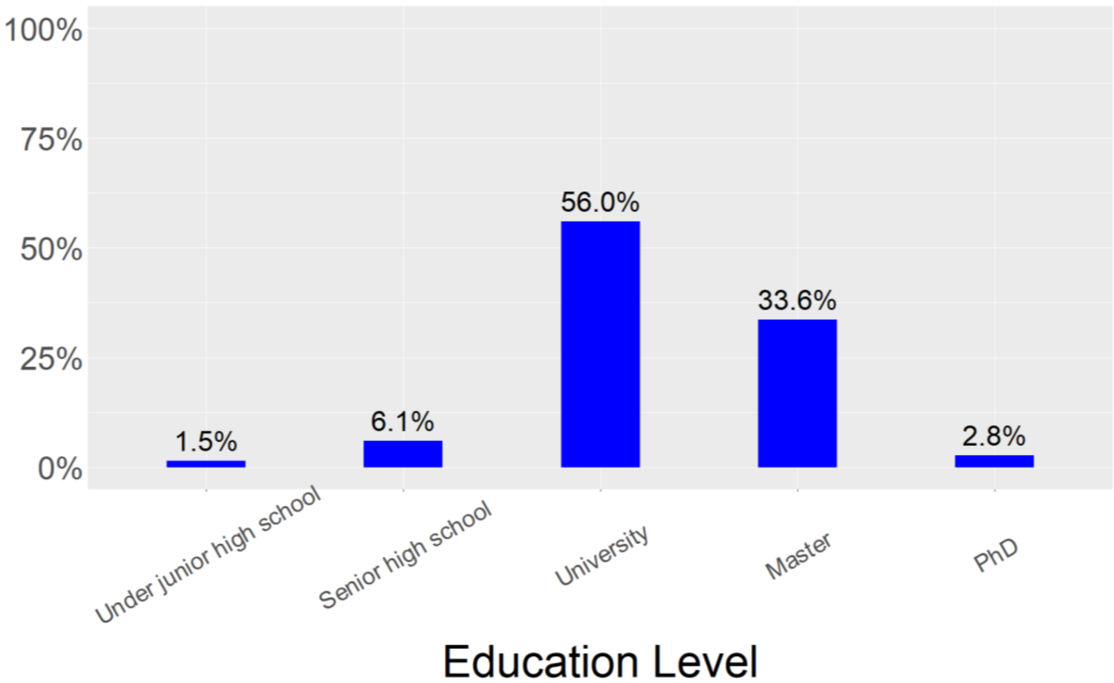

Figure 17 Education level of weighted survey data

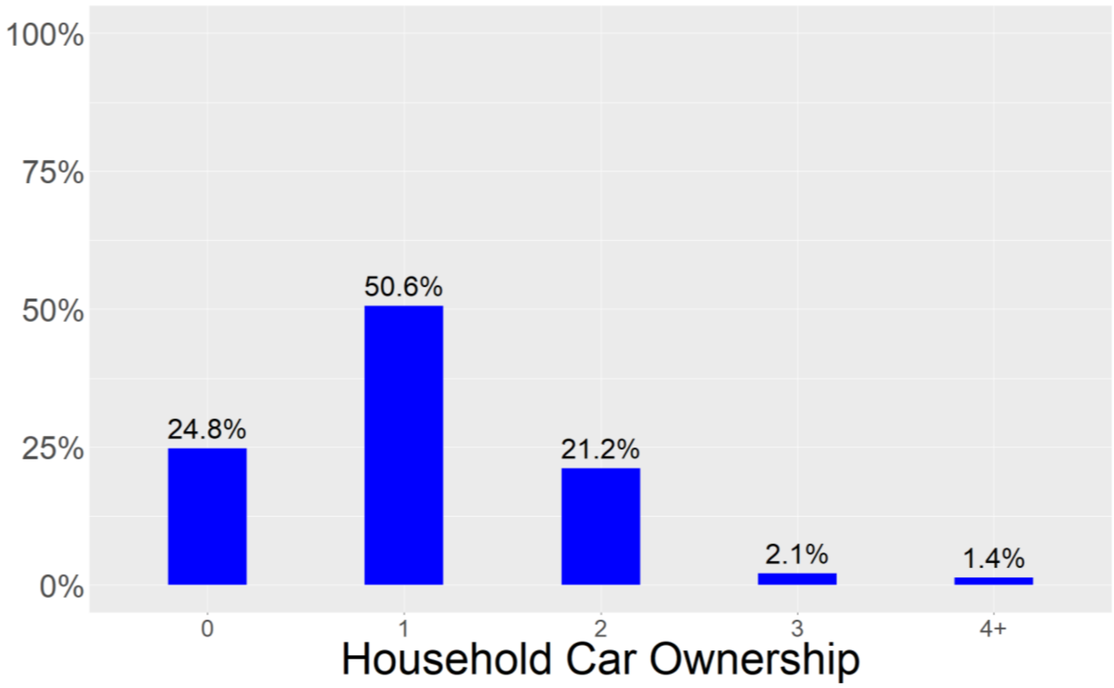

Figure 18 Household car ownership of weighted survey data

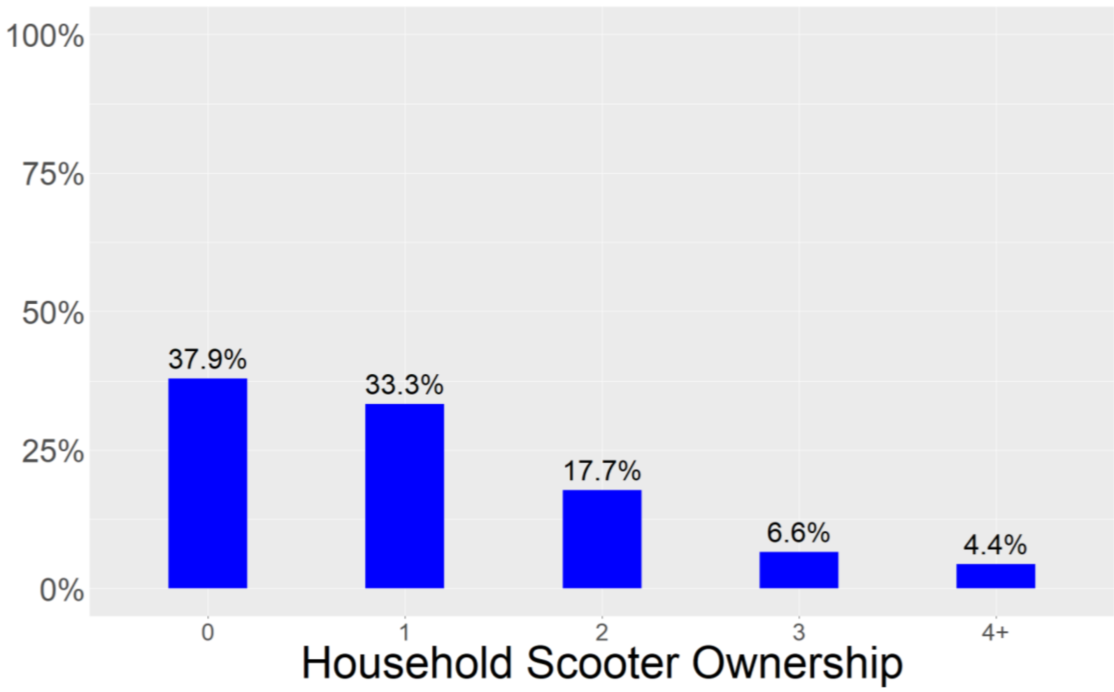

Figure 19 Household scooter ownership of weighted survey data

4.2 Stated choice experiment analysis

4.2.1 Attitude toward SAV

Regarding the respondents' awareness and acceptance of the AV and SAV using weighted survey data shown in Figure 20. These questions were asked before proposing the detailed features of SAVs in order to understand residents' awareness and attitude toward the AV and SAV in the Taipei metropolitan area.

Regarding the awareness of the AV and SAV, there are approximately 90% of respondents of all ages aware of the AV on average, and over 50% aware of the SAV on average. Among all three age groups, the respondents over age 50 are the most aware of both AV and SAV. Regarding the acceptance of the AV and SAV, there are approximately over 65% acceptance of AV and approximately over 40% acceptance of SAV among respondents who are aware of AV and SAV in all three age groups. Among all three age groups, the respondents from age 15 to 30 are the most acceptable to both AV and SAV.

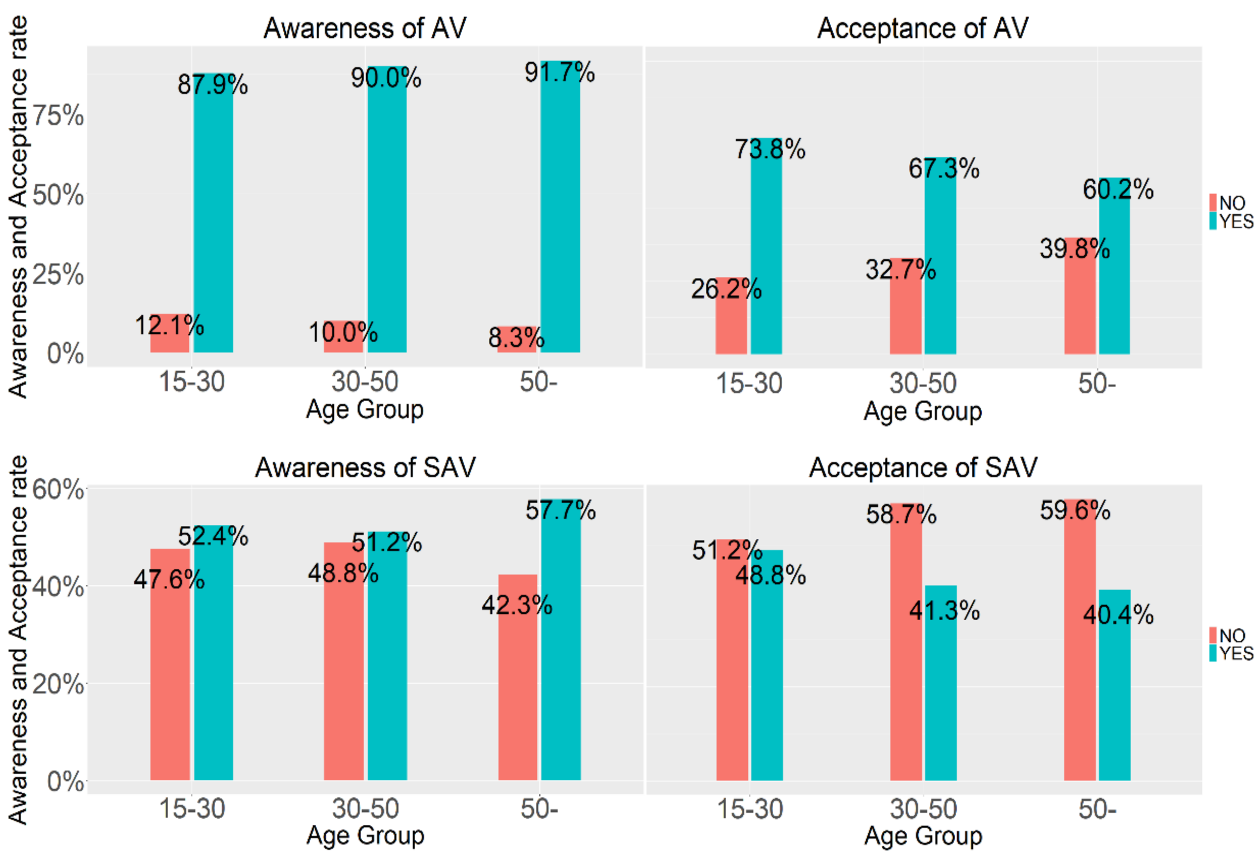

Figure 20 Awareness and acceptance rate of AV and SAV

4.2.2 Change of Mode choice behavior

For the stated mode choice experiments in four scenarios with two different SAV fare rates (i.e., 4 and 8 NTD/km) and two different waiting times (i.e., 5 and 10 minutes, SAV with ride-sharing will multiply 1.2). The statistics of all three alternatives in the stated mode choice experiment is shown in Figure 21 using weighted survey data. Overall, most of the respondents still prefer to use their current mode. The shift to SAV with ride-sharing is higher than SAV without ride-sharing, it is because the cost of SAV with ride-sharing is almost half of SAV without ride-sharing and the waiting time is only a subtle difference.

In scenario 1, with lower SAV fare rate and less waiting time has the least respondents maintain their current mode. Thus, there are over 40% would like to shift to both SAVs alternatives, especially to SAV with ride-sharing. In scenario 2 and 3, there is almost a similar share of all alternatives. Scenario 3 with lower SAV fare rate and longer waiting time has a slightly higher shift to both SAV alternatives than scenario 2 with lower SAV fare rate and longer waiting time. In scenario 4, with both higher SAV fare rate and longer waiting time has the least shift to both SAV alternatives.

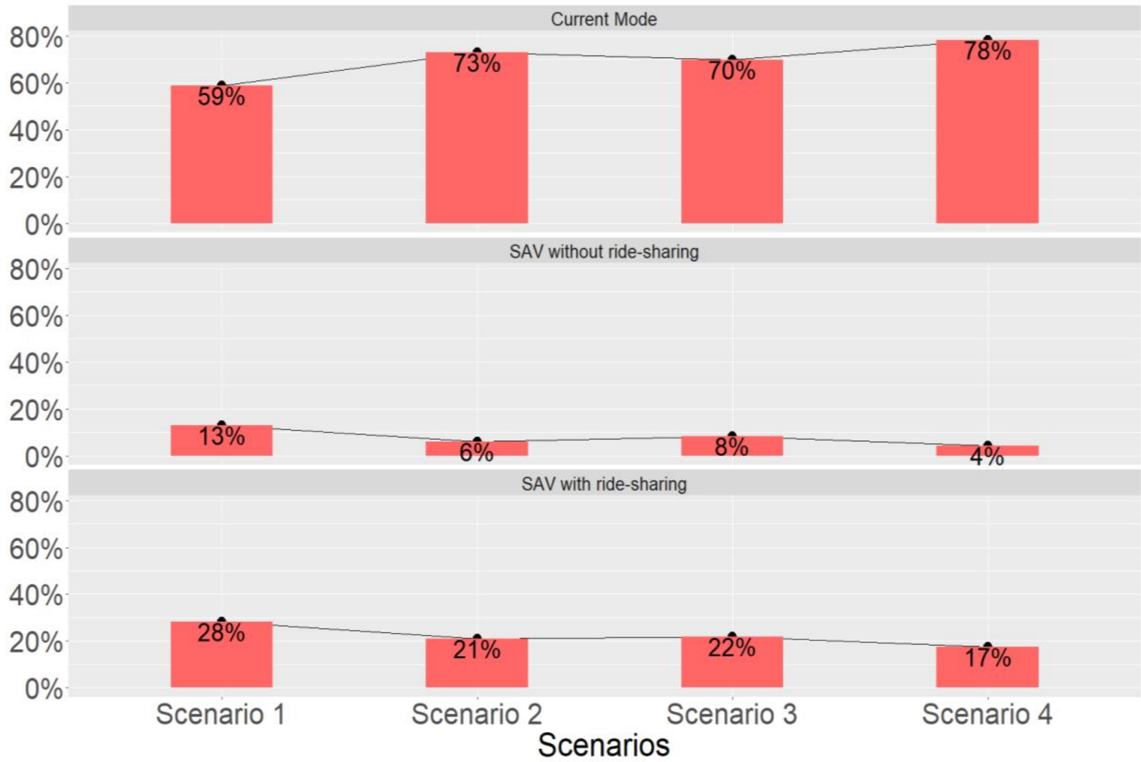

Figure 21 Stated mode choice experiments statistics in four SAV scenarios

4.2.3 Change of location choice behavior

For the stated residential choice experiments in two scenarios for each SAV alternative with the combination of two extreme attribute levels which are 4 NTD/km SAV fare rates with 5 minutes waiting time, and 8 NTD/km SAV fare rates with 10 minutes waiting time (for waiting time SAV with ride-sharing will multiply 1.2). Figure 22 and 23 show the statistics of all four alternatives in residential location choice experiments with SAV without ride-sharing and SAV with ride-sharing, respectively using the weighted survey data.

Overall, most of the respondents still prefer to stay at their current residential location and use their current mode. The alternatives of not moving but shift to SAV and moving closer to the most frequent destination have a similar share in both scenarios with both SAV alternatives. In contrast, the alternative of moving farther from the most frequent destination has the least share. This trend might because although moving farther has lower property price, travel cost and the travel time will be higher thus respondents might perceive those short-term costs like travel cost and travel time more than long-term cost like property cost.

For the residential location choice with SAV without ride-sharing shown in Figure 22, in scenario 1 with lower SAV fare rate and less waiting time has over 70% respondents maintain their current residential location and mode, and 17% of respondents willing to move either farther from or closer to their most frequent trip destination. In scenario 2 with doubling the SAV fare rate and waiting time, almost 80% of respondents would like to maintain their current situation, and only 13% of respondents would like to relocate especially moving closer to their most frequent trip destination. It is worth noting that the alternative of moving closer to their most frequent trip destination does not change through scenario 1 and 2. It is probably because moving closer has a shorter travel time that results in less travel cost, which makes little difference between the two scenarios.

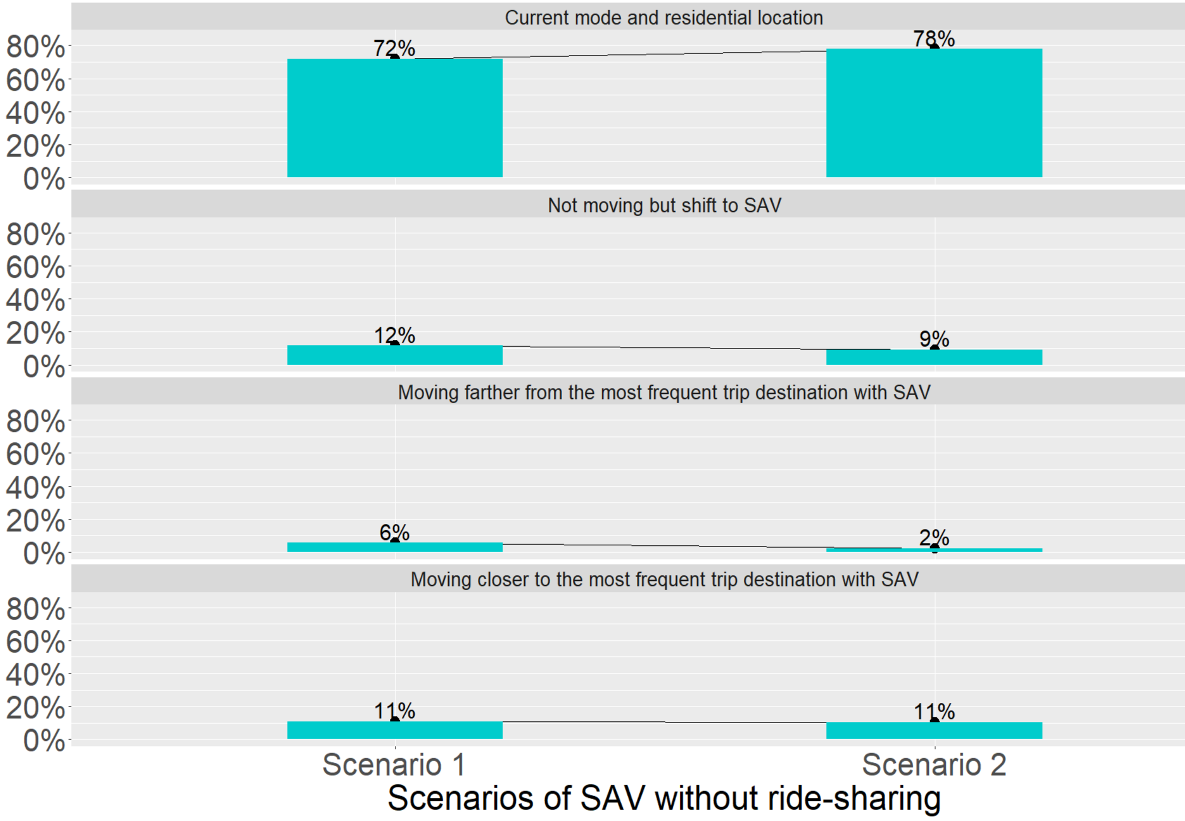

Figure 22 Stated residential locatioc choice experiments statistics in two SAV without ride-sharing scenarios

For the residential location choice with SAV with ride-sharing shown in Figure 23, in scenario 1 with lower SAV fare rate and less waiting time has almost 60% respondents maintain their current residential location and mode, and 23% of respondents willing to move either farther from or closer to their most frequent trip destination. In scenario 2 with doubling the SAV fare rate and waiting time, over 70% of respondents would like to maintain their current situation, and only 16% of respondents would like to relocate especially moving closer to their most frequent trip destination. Compare to the SAV without ride-sharing, respondents in the choice experiment with SAV with ride-sharing are more willing to relocate, and the share of relocation reduce more in both scenarios. This trend might because the travel cost of SAV with ride-sharing is almost half of SAV without ride-sharing and the waiting time is only a subtle difference thus respondents are more likely to relocate with relative lower travel cost and become more unlikely to relocate if SAV fare rate increases.

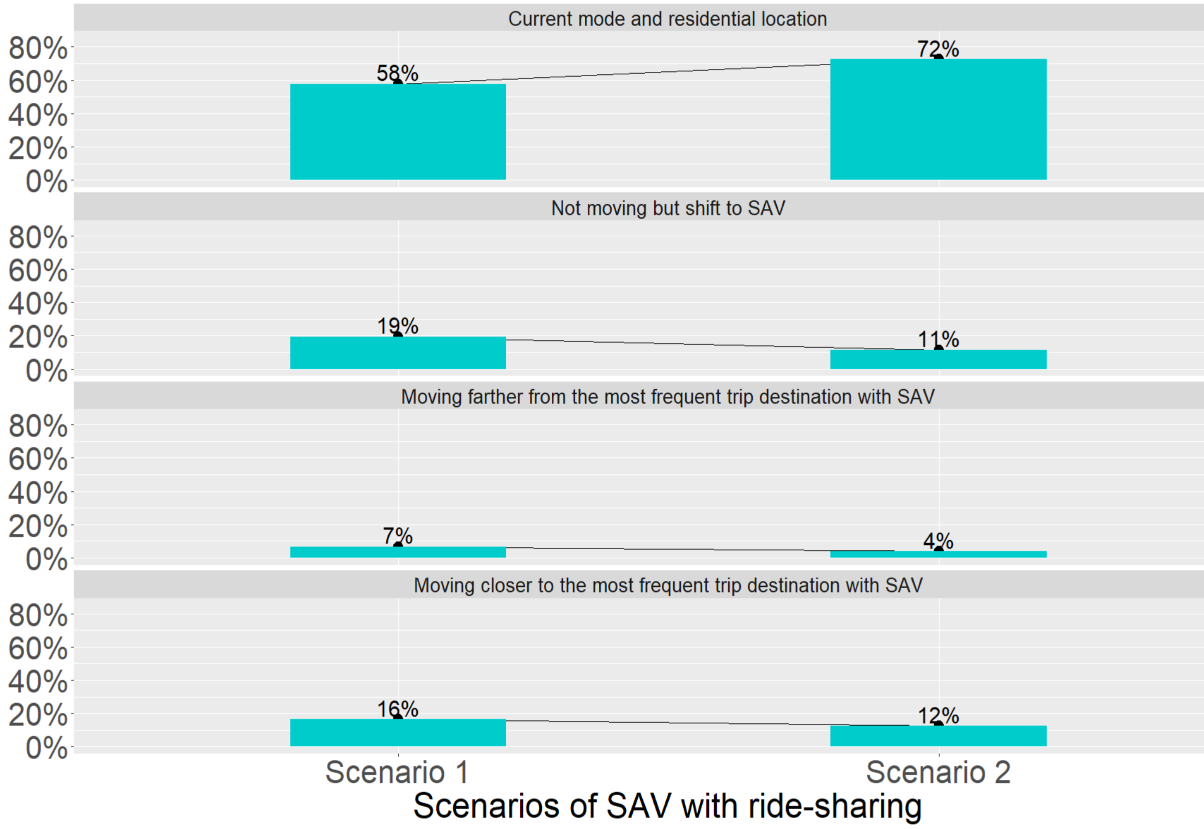

Figure 23 Stated residential location choice experiments statistics in two SAV with ride-sharing scenarios

Chapter 5. Model Estimation

In this chapter, the specification and estimation of two mode choice models, including RP-SP combined mode choice model and SP mode choice model, and two SP residential location choice models will be elaborated. Firstly, the correlation of the variables that will be specified in models will be tested in order to avoid correlated variables in models. Secondly, the two mode choice models and two residential location choice models will be developed and estimated using uncorrelated variables based on the previous correlation test.

5.1 Variables correlation test

5.1.1 Correlation test for mode choice models

For the correlation among all variables of the RP-SP combined and SP mode choice model that will be potentially tested, travel cost is highly correlated with in-vehicle time with a correlation over 0.6 because the travel cost is calculated based on the distance, namely in-vehicle travel time. Therefore, the in-vehicle generalized cost and out-of-vehicle generalized cost are used to estimate the models above. In-vehicle generalized cost is composed of in-vehicle time and travel cost. Out-of-vehicle generalized cost is composed of out-of-vehicle time. The value of in-vehicle and out-of-vehicle time for all modes is 3.93 and 7.86 NTD per minute, respectively, which is derived from Yu (2019).

Firstly, the correlation matrix of the RP-SP combined mode choice model with ten alternatives with eight available alternatives and both SAV alternatives is shown in Table 26. Twenty-six variables, including ten in-vehicle generalized costs, ten out-of-vehicle generalized cost for each mode and six socio-demographic variables, including two household private mode ownerships, gender and three age groups, are tested. Gender and age groups are dummy variables. Only out-of-vehicle generalized cost of walking is highly correlated with the in-vehicle generalized cost of other modes since there is no in-vehicle time for walking. Therefore, there will be no influence on model estimation.

Table 26 Correlation matrix of RP-SP combined mode choice model

Variables		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
In-Vehicle Generalized Cost	1. Private car	1	0.94	0.92	0.94	0.93	0.93	0.94	0	0.92	0.93	0.11	0.06	0.05	-0.01	0.03	0.06	-0.04	0.90	0	0	0	0.02	0.04	-0.08	0.11	-0.04
	2. Scooter	0.94	1	0.98	0.99	0.99	0.99	1	0	0.97	0.99	0.08	0.10	0.05	-0.01	0.05	0.06	-0.04	0.96	0	0	0.01	0.02	0.03	-0.07	0.07	-0.01
	3. Train	0.92	0.98	1	0.98	0.98	0.97	0.98	0	0.96	0.97	0.08	0.07	0.08	-0.01	0.05	0.06	-0.04	0.96	0	0	0.03	0.04	0.04	-0.07	0.06	-0.01
	4. Taxi	0.94	0.99	0.98	1	0.99	0.99	1	0	0.97	0.99	0.08	0.07	0.05	-0.08	0.05	0.06	-0.04	0.96	0	0	0	0.02	0.04	-0.07	0.08	-0.02
	5. Metro	0.93	0.99	0.98	0.99	1	0.99	1	0	0.97	0.99	0.08	0.07	0.05	-0.01	0.05	0.05	-0.04	0.96	0	0	0.01	0.02	0.03	-0.06	0.07	-0.02
	6. Bus	0.93	0.99	0.97	0.99	0.99	1	0.99	0	0.97	0.98	0.08	0.06	0.06	-0.01	0.05	0.11	-0.04	0.96	0	0	0.01	0.02	0.02	-0.08	0.08	-0.01
	7. Cycling	0.94	1	0.98	1	1	0.99	1	0	0.98	0.99	0.08	0.07	0.05	-0.01	0.05	0.06	-0.04	0.97	0	0	0.01	0.02	0.03	-0.07	0.07	-0.01
	8. Walking	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9. SAV No Share	0.92	0.97	0.96	0.97	0.97	0.97	0.98	0	1	1	0.08	0.07	0.05	-0.01	0.05	0.06	-0.04	0.94	0	0	0.01	0.02	0.03	-0.07	0.07	-0.01
	10. SAV Share	0.93	0.99	0.97	0.99	0.99	0.98	0.99	0	1	1	0.08	0.07	0.05	-0.01	0.05	0.06	-0.04	0.95	0	0	0.01	0.02	0.03	-0.07	0.07	-0.01
Out-of-Vehicle Generalized Cost	11. Private car	0.11	0.08	0.08	0.08	0.08	0.08	0.08	0	0.08	0.08	1	0	0	0	-0.02	0	0	0.10	0	0	-0.11	0.06	0.09	-0.05	-0.03	0.06
	12. Scooter	0.06	0.10	0.07	0.07	0.07	0.06	0.07	0	0.07	0.07	0	1	0	0	0.03	0	0	0.08	0	0	-0.02	-0.04	0.04	0	0.02	-0.02
	13. Train	0.05	0.05	0.08	0.05	0.05	0.06	0.05	0	0.05	0.05	0	0	1	0	0.02	0.01	0	0.06	0	0	0.10	0.04	0.10	0.01	0.08	-0.09
	14. Taxi	-0.01	-0.01	-0.01	-0.08	-0.01	-0.01	-0.01	0	-0.01	-0.01	0	0	0	1	-0.01	-0.02	0	-0.01	0	0	0.09	0.07	-0.08	-0.02	-0.07	0.08
	15. Metro	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0	0.05	0.05	-0.02	0.03	0.02	-0.01	1	0.01	0	0.06	0	0	0.05	0.09	-0.05	-0.01	-0.15	0.15
	16. Bus	0.06	0.06	0.06	0.06	0.05	0.11	0.06	0	0.06	0.06	0	0	0.01	-0.02	0.01	1	0	0.09	0	0	-0.09	-0.08	-0.06	-0.06	-0.02	0.07
	17. Cycling	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	0	-0.04	-0.04	0	0	0	0	0	0	1	-0.05	0	0	-0.11	-0.03	0.03	-0.02	-0.05	0.06
	18. Walking	0.90	0.96	0.96	0.96	0.96	0.96	0.97	0	0.94	0.95	0.10	0.08	0.06	-0.01	0.06	0.09	-0.05	1	0	0	0.04	0.03	0.03	-0.07	0.08	-0.02
	19. SAV No Share	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
	20. SAV Share	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Household Ownership	21. Private car	0	0.01	0.03	0	0.01	0.01	0.01	0	0.01	0.01	-0.11	-0.02	0.10	0.09	0.05	-0.09	-0.11	0.04	0	0	1	0.29	-0.08	-0.07	0	0.06
	22. Scooter	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0	0.02	0.02	0.06	-0.04	0.04	0.07	0.09	-0.08	-0.03	0.03	0	0	0.29	1	0.08	0.11	-0.09	0
Gender	23. Male	0.04	0.03	0.04	0.04	0.03	0.02	0.03	0	0.03	0.03	0.09	0.04	0.10	-0.08	-0.05	-0.06	0.03	0.03	0	0	-0.08	0.08	1	0.03	-0.01	-0.02
Age group	24. 15-30	-0.08	-0.07	-0.07	-0.07	-0.06	-0.08	-0.07	0	-0.07	-0.07	-0.05	0	0.01	-0.02	-0.01	-0.06	-0.02	-0.07	0	0	-0.07	0.11	0.03	1	-0.38	-0.42
	25. 30-50	0.11	0.07	0.06	0.08	0.07	0.08	0.07	0	0.07	0.07	-0.03	0.02	0.08	-0.07	-0.15	-0.02	-0.05	0.08	0	0	0	-0.09	-0.01	-0.38	1	-0.68
	26. Above 50	-0.04	-0.01	-0.01	-0.02	-0.02	-0.01	-0.01	0	-0.01	-0.01	0.06	-0.02	-0.09	0.08	0.15	0.07	0.06	-0.02	0	0	0.06	0	-0.02	-0.42	-0.68	1

Note: Numbers in red indicate the correlation exceeds 60% in the different variable categories. Besides, the Train means long-distance train.

Secondly, the correlation matrix of the SP combined mode choice model with three alternatives of the current and both SAV alternatives is shown in Table 27. Twenty variables including three in-vehicle generalized costs, three out-of-vehicle generalized costs for each alternative, eight dummy variables of current modes that respondents are currently in use, and six socio-demographic variables including interest in SAV, monthly household income, gender, and three age groups are tested. Gender, age groups, and interest in SAV are dummy variables. Besides, the monthly household income is imputed as the midpoint of each income category to become the continuous variable. Only the variable of interest in SAV correlates with the current mode. Out-of-vehicle generalized cost of walking is highly correlated with the in-vehicle generalized cost of current modes with a correlation over 0.6. Therefore, the variable of interest in SAV is removed in an alternative of the current mode.

Table 27 Correlation matrix of SP mode choice model

Variables		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
In-Vehicle Generalized Cost	1. Current mode	1	0.70	0.71	0.11	0	0	0.42	-0.29	0.13	0.02	-0.20	0.09	-0.12	-0.20	0.03	0.06	0.05	-0.14	0.13	-0.01
	2. SAV No Share	0.70	1	1	0.29	0	0	0.13	-0.17	0.56	-0.02	-0.02	0.01	-0.15	-0.21	0.18	0.03	0.03	-0.07	0.07	-0.01
	3. SAV Share	0.71	1	1	0.30	0	0	0.13	-0.17	0.57	-0.02	-0.02	0.01	-0.15	-0.22	0.18	0.03	0.03	-0.07	0.07	-0.01
Out-of-Vehicle Generalized Cost	4. Current mode	0.11	0.29	0.30	1	0	0	-0.40	-0.26	0.20	-0.02	0.48	0.30	-0.05	-0.23	0.62	-0.14	-0.06	0.01	-0.09	0.08
	5. SAV No Share	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6. SAV Share	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Current mode	7. Private car	0.42	0.13	0.13	-0.40	0	0	1	-0.32	-0.10	-0.07	-0.43	-0.29	-0.13	-0.14	-0.41	0.18	0.07	-0.18	0.10	0.05
	8. Scooter	-0.29	-0.17	-0.17	-0.26	0	0	-0.32	1	-0.06	-0.04	-0.26	-0.18	-0.08	-0.08	-0.25	-0.09	0.18	0.07	-0.02	-0.03
	9. Train	0.13	0.56	0.57	0.20	0	0	-0.10	-0.06	1	-0.01	-0.08	-0.05	-0.02	-0.02	0.09	0.12	-0.02	-0.05	0.01	0.03
	10. Taxi	0.02	-0.02	-0.02	-0.02	0	0	-0.07	-0.04	-0.01	1	-0.06	-0.04	-0.02	-0.02	-0.06	-0.06	-0.08	0.02	-0.08	0.06
	11. Metro	-0.20	-0.02	-0.02	0.48	0	0	-0.43	-0.26	-0.08	-0.06	1	-0.24	-0.11	-0.11	0.52	-0.09	-0.13	0.10	-0.04	-0.04
	12. Bus	0.09	0.01	0.01	0.30	0	0	-0.29	-0.18	-0.05	-0.04	-0.24	1	-0.07	-0.07	0.27	-0.08	-0.06	0.07	0	-0.05
	13. Cycling	-0.12	-0.15	-0.15	-0.05	0	0	-0.13	-0.08	-0.02	-0.02	-0.11	-0.07	1	-0.03	-0.10	0.01	-0.01	-0.01	-0.11	0.12
	14. Walking	-0.20	-0.21	-0.22	-0.23	0	0	-0.14	-0.08	-0.02	-0.02	-0.11	-0.07	-0.03	1	-0.11	0.02	-0.05	0.03	0	-0.02
SAV Intereset	15. SAV Interest	0.03	0.18	0.18	0.62	0	0	-0.41	-0.25	0.09	-0.06	0.52	0.27	-0.10	-0.11	1	-0.12	-0.09	0.03	-0.05	0.02
Income	16. Income	0.06	0.03	0.03	-0.14	0	0	0.18	-0.09	0.12	-0.06	-0.09	-0.08	0.01	0.02	-0.12	1	-0.03	-0.04	-0.05	0.09
Gender	17. Male	0.05	0.03	0.03	-0.06	0	0	0.07	0.18	-0.02	-0.08	-0.13	-0.06	-0.01	-0.05	-0.09	-0.03	1	0.03	-0.01	-0.02
Age group	18. 15-30	-0.14	-0.07	-0.07	0.01	0	0	-0.18	0.07	-0.05	0.02	0.10	0.07	-0.01	0.03	0.03	-0.04	0.03	1	-0.38	-0.42
	19. 30-50	0.13	0.07	0.07	-0.09	0	0	0.10	-0.02	0.01	-0.08	-0.04	0	-0.11	0	-0.05	-0.05	-0.01	-0.38	1	-0.68
	20. Above 50	-0.01	-0.01	-0.01	0.08	0	0	0.05	-0.03	0.03	0.06	-0.04	-0.05	0.12	-0.02	0.02	0.09	-0.02	-0.42	-0.68	1

Note: Numbers in red indicate the correlation exceeds 60% in the different variable categories.

5.1.2 Correlation test for residential location choice model

For the correlation among all variables of the residential location choice models with the introduction of SAV without ride-sharing and SAV with ride-sharing that will be potentially tested, monthly travel cost is highly correlated with the in-vehicle time with a correlation around 0.7 because the monthly travel cost is calculated based on the distance, namely the in-vehicle travel time. Therefore, the ratio of monthly travel cost to household income is used to estimate the models above.

The correlation matrices of two residential location choice models, including the introduction of SAV without ride-sharing and with ride-sharing with four alternatives of residential location choices, are shown in Table 28 and 29. Overall, fifteen variables, including four property cost, four ratios of monthly travel cost to household income, four travel time for each alternative, and four dummy variables of city of residence of respondents, are tested. There are no variables with correlation exceed 0.6 in different variable categories, which indicate that the conversion of monthly travel cost to ratios of monthly travel cost to household income effectively reduces the correlation between monthly travel cost and travel time.

Table 28 Correlation matrix of residential location choice by introducing SAV without ride-sharing

Variables		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Property Cost	1. Current	1.00	0.98	0.95	-0.03	-0.10	-0.13	-0.12	-0.08	-0.04	-0.04	-0.01	0.20	-0.14	-0.03	-0.09
	2. Move Farther	0.98	1.00	0.86	-0.04	-0.10	-0.13	-0.11	-0.14	-0.09	-0.11	0.00	0.23	-0.18	-0.04	-0.07
	3. Move Closer	0.95	0.86	1.00	-0.02	-0.10	-0.10	-0.13	0.01	0.04	0.05	-0.03	0.13	-0.05	-0.01	-0.11
Ratio of Monthly Travel Cost to Income	4. Current	-0.03	-0.04	-0.02	1.00	0.58	0.60	0.59	0.22	0.22	0.21	0.19	-0.07	0.06	-0.02	0.03
	5. Only mode shift	-0.10	-0.10	-0.10	0.58	1.00	0.96	0.94	0.29	0.31	0.30	0.27	-0.05	0.02	-0.02	0.06
	6. Move Farther	-0.13	-0.13	-0.10	0.60	0.96	1.00	0.93	0.35	0.38	0.38	0.32	-0.08	0.06	-0.02	0.05
	7. Move Closer	-0.12	-0.11	-0.13	0.59	0.94	0.93	1.00	0.26	0.23	0.22	0.27	0.00	0.00	-0.04	0.02
Travel Time	8. Current	-0.08	-0.14	0.01	0.22	0.29	0.35	0.26	1.00	0.76	0.76	0.62	-0.12	0.13	0.00	-0.01
	9. Only mode shift	-0.04	-0.09	0.04	0.22	0.31	0.38	0.23	0.76	1.00	0.99	0.80	-0.15	0.12	0.01	0.05
	10. Move Farther	-0.04	-0.11	0.05	0.21	0.30	0.38	0.22	0.76	0.99	1.00	0.72	-0.18	0.15	0.02	0.04
	11. Move Closer	-0.01	0.00	-0.03	0.19	0.27	0.32	0.27	0.62	0.80	0.72	1.00	0.02	-0.08	-0.04	0.10
City of Residence	12. Taipei	0.20	0.23	0.13	-0.07	-0.05	-0.08	0.00	-0.12	-0.15	-0.18	0.02	1.00	-0.72	-0.14	-0.41
	13. New Taipei	-0.14	-0.18	-0.05	0.06	0.02	0.06	0.00	0.13	0.12	0.15	-0.08	-0.72	1.00	-0.09	-0.28
	14. Keelung	-0.03	-0.04	-0.01	-0.02	-0.02	-0.02	-0.04	0.00	0.01	0.02	-0.04	-0.14	-0.09	1.00	-0.05
	15. Taoyuan	-0.09	-0.07	-0.11	0.03	0.06	0.05	0.02	-0.01	0.05	0.04	0.10	-0.41	-0.28	-0.05	1.00

Table 29 Correlation matrix of residential location choice by introducing SAV with ride-sharing

Variables		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Property Cost	1. Current	1	0.98	0.95	-0.03	-0.10	-0.12	-0.12	-0.08	-0.04	-0.04	-0.01	0.20	-0.14	-0.03	-0.09
	2. Move Farther	0.98	1	0.86	-0.04	-0.10	-0.13	-0.11	-0.14	-0.09	-0.11	0.00	0.23	-0.18	-0.04	-0.07
	3. Move Closer	0.95	0.86	1	-0.02	-0.10	-0.10	-0.13	0.01	0.04	0.05	-0.03	0.13	-0.05	-0.01	-0.11
Ratio of Monthly Travel Cost to Income	4. Current	-0.03	-0.04	-0.02	1	0.58	0.60	0.59	0.22	0.22	0.21	0.19	-0.07	0.06	-0.02	0.03
	5. Only mode shift	-0.10	-0.10	-0.10	0.58	1	0.97	0.95	0.30	0.32	0.32	0.29	-0.05	0.02	-0.02	0.06
	6. Move Farther	-0.12	-0.13	-0.10	0.60	0.97	1	0.93	0.36	0.39	0.39	0.33	-0.08	0.06	-0.02	0.05
	7. Move Closer	-0.12	-0.11	-0.13	0.59	0.95	0.93	1	0.27	0.24	0.23	0.28	0.00	-0.01	-0.04	0.02
Travel Time	8. Current	-0.08	-0.14	0.01	0.22	0.30	0.36	0.27	1	0.76	0.76	0.62	-0.12	0.13	0.00	-0.01
	9. Only mode shift	-0.04	-0.09	0.04	0.22	0.32	0.39	0.24	0.76	1	0.99	0.80	-0.15	0.12	0.01	0.05
	10. Move Farther	-0.04	-0.11	0.05	0.21	0.32	0.39	0.23	0.76	0.99	1	0.72	-0.18	0.15	0.02	0.04
	11. Move Closer	-0.01	0.00	-0.03	0.19	0.29	0.33	0.28	0.62	0.80	0.72	1	0.02	-0.08	-0.04	0.10
City of Residence	12. Taipei	0.20	0.23	0.13	-0.07	-0.05	-0.08	0.00	-0.12	-0.15	-0.18	0.02	1	-0.72	-0.14	-0.41
	13. New Taipei	-0.14	-0.18	-0.05	0.06	0.02	0.06	-0.01	0.13	0.12	0.15	-0.08	-0.72	1	-0.09	-0.28
	14. Keelung	-0.03	-0.04	-0.01	-0.02	-0.02	-0.02	-0.04	0.00	0.01	0.02	-0.04	-0.14	-0.09	1	-0.05
	15. Taoyuan	-0.09	-0.07	-0.11	0.03	0.06	0.05	0.02	-0.01	0.05	0.04	0.10	-0.41	-0.28	-0.05	1

Note: Numbers in red indicate the correlation exceed 60% in the different variable sections

5.2 Mode choice model estimation

5.2.1 RP-SP combined mode choice model

Above all, the RP-SP model with ten alternatives will be developed after the correlation test. The model is developed incrementally by adding each variable one by one with a standard of significance set by lower than 5% ($p < 0.05$). The variables of in-vehicle generalized cost and out-of-vehicle generalized cost are scaled-down by dividing 100 in order to have uniform coefficient scale. Besides, the availability of each conventional mode in each district is identified.

Firstly, the base model is built with alternative specific constants (ASC) which private car is set as a base case, in-vehicle generalized cost $(IVGC)$, and out-of-vehicle generalized cost $(OVGC)$. All the variables above have alternative specific parameters that this research assumes in- / out-of-vehicle generalized costs are perceived differently in each alternative. The coefficient with an unreasonable sign like the bus, which has a positive sign that means the increase in the in-vehicle travel time or cost will increase the utility of using the bus that is very unlikely, was withdrawn. Moreover, insignificant parameters are also withdrawn with the in-vehicle generalized cost of train, taxi, and walk, and the out-of-vehicle generalized cost of the private car, scooter, taxi, metro, bus, and bike. However, the alternative specific constants of train and bus are insignificant, but they will be retained until the last step of the estimation.

Secondly, the socio-demographic variables including household private mode ownerships for private car $(CarOwn)$ and scooter $(ScooterOwn)$, gender with the female as a base case $(Male)$, and three age groups with the age of 15 to 30 as a base case, 30 to 50, and above 50 are added one by one in the model. All the variables above have alternative specific parameters assuming that all personal attributes are perceived differently in each alternative. For household private car ownership, and scooter ownership, both signs of the coefficients are positive, and the parameters are both significant which implies the more private modes the household has, the more likely to use private modes. For the gender, apart from the female is set as a base case, the parameter of the gender of the private car is also set as a base case among all alternatives. Only parameters of scooter and metro are significant. For the age groups, apart from age 15 to 30 is set as a base case, the parameter of the age of the private car is also set as a base case among all alternatives. Parameters of metro, bus, bike, walk, SAV without and with ride-sharing are significant from age group 30 to 50. Parameters of scooter, taxi, metro, bike, walk, SAV with ride-sharing are significant from the age group above 50.

Finally, the alternative specific constants of bus and train are still insignificant; thus, they are removed. Moreover, in order to match the modal split of Taipei metropolitan area by national household travel survey, the alternative-specific constants are calibrated as Table 30 shows. Therefore, the modal split after calibration with survey data becomes closer to the modal split of the national household travel survey shown in Table 31. The final model specification is shown in Equation 9 to 18, and the final model estimation is shown in Table 32.

Table 30 Alternative-specific constants before and after calibration

Alternative-specific constants	Before Calibration	After Calibration
$ASC_{scooter}$	1.18 (6.41) ***	2.925
ASC_{taxi}	-10.6 (-12.1) ***	-8.762
ASC_{metro}	1.22 (8.47) ***	0.547
ASC_{bike}	0.886 (2.98) ***	1.687
ASC_{walk}	4.37 (14.5) ***	12.963

Note: Number in bracket are t-test value and *** implies p-value < 0.005

Table 31 Modal split before and after calibration compare to national household travel survey (Taiwan Ministry of Transportation, 2016)

	Private mode		Public transit				Active mode	
Modal Split	Private car	Scooter	Train	Taxi	Metro	Bus	Bike	Walk
National household travel survey	18%	35%	2.5%	4%	12%	14%	3%	10%
Before Calibration	34.6%	16.7%	1.7%	1%	26.1%	13.4%	3.1%	3.4%
After Calibration	23.4%	35%	1.7%	4%	12%	11.1%	3%	10%

$$V_{car} = \beta_{IVGC,car}\frac{IVGC_{car}}{100} + \beta_{carown}CarOwn \tag{9}$$

$$V_{scooter} = ASC_{scooter} + \beta_{IVGC,scooter}\frac{IVGC_{scooter}}{100} + \beta_{scooterown}ScooterOwn + \beta_{male,scooter}Male + \beta_{50+,scooter}Age50_{+} \tag{10}$$

$$V_{train} = \beta_{OVGC,train}\frac{OVGC_{train}}{100} \tag{11}$$

$$V_{taxi} = ASC_{taxi} + \beta_{age50+,taxi}Age50_{+} \tag{12}$$

$$V_{metro} = ASC_{metro} + \frac{IVGC_{metro}}{100} + \beta_{male,metro}Male + \beta_{age30-50,metro}Age30-50 + \beta_{age50+,metro}Age50_{+} \tag{13}$$

$$V_{bus} = \beta_{IVGC,bus}\frac{IVGC_{bus}}{100} + \beta_{age30-50,bus}Age30-50 \tag{14}$$

$$V_{bike} = ASC_{bike} + \beta_{IVGC,bike}\frac{IVGC_{bike}}{100} + \beta_{age30-50,bike}Age30-50 + \beta_{age50+,bike}Age50_{+} \tag{15}$$

$$V_{walk} = ASC_{walk} + \beta_{OVGC,walk}\frac{OVGC_{walk}}{100} + \beta_{age50+,walk}Age50_{+} \tag{16}$$

$$V_{SAVnoShare} = ASC_{SAVnoShare} + \beta_{IVGC,SAVnoShare}\frac{IVGC_{SAVnoShare}}{100} + \beta_{OVGC,SAVnoShare}\frac{OVGC_{SAVnoShare}}{100} + \beta_{age30-50,SAVnoShare}Age30-50 \tag{17}$$

$$V_{SAVshare} = ASC_{SAVshare} + \beta_{IVGC,SAVshare}\frac{IVGC_{SAVshare}}{100} + \beta_{OVGC,SAVshare}\frac{OVGC_{SAVshare}}{100} + \beta_{age30-50,SAVnoShare}Age30-50 + \beta_{age50+,SAVshare}Age50_{+} \tag{18}$$

Note: The alternative-specific constant of the private car alternative is set as a base case, and parameters of the private car alternatives, including all age groups are set as a base case. Moreover, parameters of age 15 to 30 is set as a base case relative to $Age30-50$ and $Age50+$

Table 32 Estimation of the RP-SP combined mode choice model

Alternative-specific constant	Coefficient (t-test)
$ASC_{scooter}$	2.925
ASC_{taxi}	-8.762
ASC_{metro}	0.547
ASC_{bike}	1.687
ASC_{walk}	12.963
$ASC_{SAVnoShare}$	1.29 (5.76) ***
$ASC_{SAVshare}$	1.32 (7.43) ***
In-vehicle generalized cost	
$\beta_{IVGC,car}$	-1.23 (-18.3)***
$\beta_{IVGC,scooter}$	-3.55 (-26.8)***
$\beta_{IVGC,metro}$	-1.85 (-15.7)***
$\beta_{IVGC,bus}$	-1.44 (-17.5)***
$\beta_{IVGC,bike}$	-2.54 (-17.7)***
$\beta_{IVGC,SAVnoShare}$	-1.35 (-16.7)***
$\beta_{IVGC,SAVshare}$	-1.34 (-19.5)***
Out-of-vehicle generalized cost	
$\beta_{OVGC,train}$	-1.81 (-19.3)***
$\beta_{OVGC,walk}$	-1.3 (-8.79)***
$\beta_{OVGC,SAVnoShare}$	-1.41 (-4.96)***
$\beta_{OVGC,SAVshare}$	-0.806 (-5.16)***
Household private mode ownership	
β_{carown}	0.667 (13.9)***
$\beta_{scooterown}$	0.529 (9.82)***
Gender	
$\beta_{male,scooter}$	0.951 (8.92)***
$\beta_{male,metro}$	-0.538 (-6.48)***
Age	
$\beta_{age30-50,metro}$	-1.14 (-10.1)***
$\beta_{age30-50,bus}$	-0.799 (-6.76)***
$\beta_{age30-50,bike}$	-1.28 (-3.25)***
$\beta_{age30-50,SAVnoShare}$	-0.899 (-7.03)***
$\beta_{age30-50,SAVshare}$	-0.58 (-4.74)***
$\beta_{age50+,scooter}$	-0.439 (-3.92)***
$\beta_{age50+,taxi}$	5.4 (6.53)***
$\beta_{age50+,metro}$	-0.852 (-7.72)***
$\beta_{age50+,bike}$	0.908 (3.2)***
$\beta_{age50+,walk}$	-1.4 (-4.35)***
$\beta_{age50+,SAVshare}$	0.564 (5.07)***
Initial log likelihood: -2283 Final log likelihood: -1314 Rho-square: 0.424	

Note: Significance is marked by * (p-value < 0.05), ** (p-value < 0.01), and *** (p-value < 0.005).

For the interpretation of the final RP-SP combined mode choice model shown in Table 32. Regarding the alternative-specific constants, compared to the private car, scooter, metro, and bike have alternative-specific constants within three which are small magnitude that probably contain less unobserved attributes, taste variation or measurement error. However, the alternative-specific constants of taxi and walk has a larger magnitude of value, indicating there might be more unobserved reasons are measured in this model.

Regarding the in-vehicle generalized cost, it is evident that most of the alternatives including private car, scooter, metro, bus, bike, SAV without and with ride-sharing have negative coefficients indicating the more in-vehicle time or travel cost spent, the less likely to choose that alternative. Among all alternatives above, the scooter has the minimum coefficient, which means with increasing the same amount of in-vehicle time or travel cost, the utility of the scooter will reduce the most. Besides, SAV without and with ride-sharing have almost the same coefficients that implies respondents perceived the in-vehicle time and cost of these two alternatives equally.

Regarding out-of-vehicle generalized cost, train, walk, SAV without and with ride-sharing have negative coefficients indicating the more out-of-vehicle time spent, the less likely to choose that alternative. Among all alternatives above, the train has the minimum coefficient, which means with increasing the same amount of out-of-vehicle time, the utility of the train will reduce the most. Besides, SAV without ride-sharing has a smaller coefficient than SAV with ride-sharing that implies the increase in the same amount of out-of-vehicle time of both SAV alternatives, SAV without ride-sharing are less likely to be chosen than SAV with ride-sharing.

For the socio-demographic parameters regarding household private ownership and gender, coefficients of the household private car ownership and scooter ownership are both positive implying that the more private cars and scooters the household owns, the private car and scooter are more likely to be chosen which is reasonable. Regarding the parameter of gender, compared to private car and female, the male is more likely to choose the scooter and less likely to choose the metro.

Furthermore, regarding the age group, compared to the private car and the age from 15 to 30, the respondents from age 30 to 50 are less likely to choose metro, bus, bike, SAV without and with ride-sharing, probably because the people in this age group are more affordable for private modes and not as interested in autonomous mobility than younger age group. Besides, SAV without ride-sharing has a smaller coefficient than SAV with ride-sharing that implies the people from age 30 to 50 are less likely to choose SAV without ride-sharing than SAV with ride-sharing. It is probably because they might still prefer the cheaper alternative, namely, SAV with ride-sharing. For age above 50 compare to private car and age 15 to 30, scooter, metro, and walk are less likely to be chosen probably because people of this age group have their private car thus not use public transit which needs more travel time. On the other hand, Taxi, bike, and SAV with ride-sharing are more likely to be chosen. It is probably because they are affordable for taxi and use a bike to travel nearby their home. However, the result shows that people above age 50 are more interested in using SAV with ride-sharing, which have not been found in previous related research. Overall, the youngest age group are most likely to use SAV without ride-sharing, and the oldest age group are most likely to use SAV with ride-sharing.

5.2.2 SP mode choice model

After the RP-SP combined mode choice model was developed and estimated, the SP mode choice model with three alternatives which are current mode, SAV without and with ride-sharing will be developed. The model is also developed incrementally by adding each variable one by one with a standard of significance is set by lower than 5% ($p < 0.05$). The variables of in-vehicle generalized cost and out-of-vehicle generalized cost are scaled-down by dividing 100, and monthly household income is scaled-down by dividing 100,000 in order to have uniform coefficient scale.

Firstly, the base model is built with alternative specific constants (ASC) which respondents' current transport mode in use is set as a base case, in-vehicle generalized cost $(IVGC)$, and out-of-vehicle generalized cost $(OVGC)$. All the variables above have alternative specific parameters same as RP-SP combined model. After the first estimation of the base model, all parameters are reasonable and significant, which means that alternative specific constants are significant and in- / out-of-vehicle generalized cost have negative coefficients in the utility function.

Secondly, eight dummy variables of respondents' current mode in use are added to identify the effect of each current modes on the utility. All these dummy variables have alternative specific parameters assuming that each alternative is perceived differently by the users with the same current mode. Setting the current alternative and private car as a base case, for SAV without ride-sharing alternative, the significant parameters are retained with the metro $(IsMetro)$, bus $(IsBus)$, and bike $(IsBike)$. For the SAV with ride-sharing alternative, the significant parameters are retained with the scooter $(IsScooter)$, taxi $(IsTaxi)$, bus $(IsBus)$, and bike $(IsBike)$.

Thirdly, the socio-demographic variables including, dummy variable of interest toward SAV, monthly household income $(Income)$, gender with the female as a base case $(Male)$, and three age groups with the age of 15 to 30 as a base case, 30 to 50, and above 50 are added one by one in the model. All the variables above have alternative specific parameters same as the RP-SP combined model.

For dummy variable of interest toward SAV, all parameters are insignificant, which indicates that whether people who are interested in SAV or not has no influence on the utility of all alternatives. For the monthly household income, compared to the current alternative, both signs of the coefficients are positive, and the parameters are both significant which implies the more monthly household income, the more likely to use SAV alternatives. For the gender, except the female is set as a base case, the parameter of the gender of the current alternative is also set as a base case among all alternatives. Comparing to the current alternative, both parameters of SAV without and with ride-sharing have positive and significant coefficients.

For the age groups, except age 15 to 30 is set as a base case, the parameter of the age of the current alternative is also set as a base case among all alternatives. The only parameter of SAV without ride-sharing is significant from the age group 30 to 50, and the only parameter of SAV with ride-sharing is significant from the age group above 50. The final model specification is shown in Equation 19 to 21, and the final model estimation is shown in Table 33.

$$V_{current} = \beta_{IVGC,current}\frac{IVGC_{current}}{100} + \beta_{OVGC,current}\frac{OVGC_{current}}{100} \quad (19)$$

$$\begin{aligned} V_{SAVnoShare} = {} & ASC_{SAVnoShare} + \beta_{IVGC,SAVnoShare}\frac{IVGC_{SAVnoShare}}{100} + \\ & \beta_{OVGC,SAVnoShare}\frac{OVGC_{SAVnoShare}}{100} + \beta_{ismetro,SAVnoShare}IsMetro + \\ & \beta_{isbus,SAVnoShare}IsBus + \beta_{isbike,SAVnoShare}IsBike + \\ & \beta_{income,SAVnoShare}Income + \beta_{male,current}Male + \\ & \beta_{age2,SAVnoShare}Age30-50 \end{aligned} \quad (20)$$

$$\begin{aligned} V_{SAVshare} = {} & ASC_{SAVshare} + \beta_{IVGC,SAVshare}\frac{IVGC_{SAVshare}}{100} \\ & \beta_{OVGC,SAVshare}\frac{OVGC_{SAVshare}}{100} + \beta_{isscooter,SAVshare}IsScooter + \\ & \beta_{istaxi,SAVshare}IsTaxi + \beta_{isbus,SAVshare}IsBus + \beta_{isbike,SAVshare}IsBike \\ & \beta_{income,SAVshare}Income + \beta_{male,SAVshare}Male + \\ & \beta_{age50+,SAVshare}Age50+ \end{aligned} \quad (21)$$

Note: The alternative-specific constant of current alternative is set as a base case, parameters of current alternatives, including eight parameters of $IsCar$ to $IsWalk$, $Income$, all three age groups are set as a base case. Moreover, parameters of all $IsCar$ are set a base case relative to other modes, and parameters of age 15 to 30 are set as a base case relative to $Age30-50$ and $Age50+$.

Table 33 Estimation of the SP mode choice model

Alternative-specific constant	Coefficient (t-test)
$ASC_{SAVnoShare}$	-1.81 (-7.41)***
$ASC_{SAVshare}$	-1.43 (-8.33)***
In-vehicle generalized cost	
$\beta_{IVGC,current}$	-1.33 (-19.6)***
$\beta_{IVGC,SAVnoShare}$	-1.3 (-16)***
$\beta_{IVGC,SAVshare}$	-1.37 (-18.7)***
Out-of-vehicle generalized cost	
$\beta_{OVGC,current}$	-0.795 (-17)***
$\beta_{OVGC,SAVnoShare}$	-1.55 (-5.28)***
$\beta_{OVGC,SAVshare}$	-0.923 (-5.57)***
Current mode in use	
$\beta_{ismetro,SAVnoShare}$	-0.617 (-4.17)***
$\beta_{isbus,SAVnoShare}$	-0.892 (-4.96)***
$\beta_{isbike,SAVnoShare}$	-1.18 (-3.44)***
$\beta_{isscooter,SAVshare}$	-0.689 (-4.94)***
$\beta_{istaxi,SAVshare}$	-2.54 (-3.45)***
$\beta_{isbus,SAVshare}$	-0.638 (-5.45)***
$\beta_{isbike,SAVshare}$	-1.85 (-6.43)***
Monthly household income	
$\beta_{income,SAVnoShare}$	0.433 (7.12)***
$\beta_{income,SAVshare}$	0.183 (3.93)***
Gender	
$\beta_{male,SAVnoShare}$	0.236 (2.06)*
$\beta_{male,SAVshare}$	0.193 (2.45)*
Age	
$\beta_{age30-50,SAVnoShare}$	-0.452 (-3.68)***
$\beta_{age50+,SAVshare}$	0.676 (8.71)***
Initial log likelihood: -5294 Final log likelihood: -3230 Rho-square: 0.39	

Note: Significance is marked by * (p-value < 0.05), ** (p-value < 0.01), and *** (p-value < 0.005).

For the interpretation of the final SP mode choice model shown in Table 33, regarding alternative-specific constants, compared to the current alternative, the two constants of SAV are within -2 which is a small magnitude that probably contains less unobserved attributes, taste variation or measurement error.

Regarding the in-vehicle generalized cost, all alternatives have negative coefficients indicating the more in-vehicle time or travel cost spent, the less likely to choose all the alternatives. The coefficients of all alternatives are almost the same around -1.3, which implies that the change in in-vehicle time or travel cost has the same effect on the change in utility of all three alternatives. Besides, the coefficients of both SAV alternatives in the SP model and RP-SP combined model have similar coefficients of in-vehicle generalized cost.

Regarding out-of-vehicle generalized cost, all alternatives have negative coefficients. Among them, the SAV without ride-sharing has the minimum coefficient around -1.5, implying the waiting time significantly and negatively affect the utility. It is because the potential users of SAV without ride-sharing are more sensitive to out-of-vehicle time, namely waiting time to reduce the overall travel time compare to the current alternatives and SAV with ride-sharing. Besides, the coefficients of both SAV alternatives in the SP model and RP-SP combined model have similar coefficients of out-of-vehicle generalized cost.

Regarding the parameters of eight dummy variables that respondents are currently in use. Compared to the current alternative and the dummy variables of the private car, all coefficients are negative, which implies that the current private car users are the most likely to choose both SAV alternatives. It is probably because most of the private car users are more able to afford SAV alternatives which are more expensive than public transit. In contrast, the users of the bike are more unlikely to use both SAV alternatives probably because the bike is the cheapest alternatives among public transit that result in the lack of affordability of both SAV alternatives. Besides, the coefficient of the dummy variable of the taxi in an alternative of SAV with ride-sharing is the minimum which means the current taxi users are most unlikely to choose SAV with ride-sharing. It is probably because the current taxi users are more time-sensitive since SAV ride-sharing has additional time for picking up other passengers.

For the socio-demographic parameters regarding monthly household income and gender, compared to the current alternative, coefficients of monthly household income of both SAV alternatives are positive, implying that the higher the monthly household income, the more likely to use both SAV alternatives, significantly shift to SAV without ride-sharing. It is reasonable because the value of the time of higher-income people tends to lower the travel time regardless of the higher travel cost. Regarding the parameter of gender, compared to the current alternative and female, the male is more likely to choose both SAV alternatives.

Furthermore, regarding the age group, compared to the current alternative and the age from 15 to 30, the respondents from age 30 to 50 are less likely to choose SAV without ride-sharing with the coefficient of -0.45. This probably because the people in this age group are more affordable for private modes and not as interested in autonomous mobility than the younger age group. The coefficient is the half of the same parameter in RP-SP combined model, which has the coefficient around -0.9. For age above 50 compared to the current alternative and age 15 to 30, SAV with ride-sharing are more likely to be chosen with the coefficient of 0.68. This result is similar to the same parameter in RP-SP combined model, which has the coefficient around 0.56. Overall, the youngest age group are most likely to use SAV without ride-sharing, and the oldest age group are most likely to use SAV with ride-sharing. This result is the same as the result of RP-SP combined model.

Generally, the RP-SP combined model and SP model have a similar result. However, each model has its own error due to the slight difference in estimated alternatives and variables.

5.3 SP residential location choice model estimation

5.3.1 Model with introduction of SAV without ride-sharing

Two residential location choice models, including residential location choice with the introduction of SAV without and with ride-sharing with four alternatives in each model, will be developed after the correlation test. Both models are developed incrementally by adding each variable one by one with a standard of significance is set by lower than 5% ($p < 0.05$). The variables of property cost including own property cost and monthly rent are scaled-down by dividing 100,000, the ratio of monthly travel cost to monthly household income and travel time are scaled-down by dividing 100 in order to have uniform coefficient value.

Firstly for the residential location choice with the introduction of SAV without ride-sharing, the base model is built with alternative specific constants (ASC) which the current alternative is set as a base case, property cost (PC), the ratio of monthly travel cost to monthly household income $(MTCtoIncome)$, and travel time (TT). All variables above have alternative specific parameters that this research assumes they are perceived differently in each alternative. Insignificant parameters, including all property cost and travel time of not moving but shift to SAV alternative, are withdrawn. All four ratio of monthly travel cost to monthly household income alternatives is significant and retained.

Secondly, four dummy variables of cities where respondents' currently live are added to identify the effect of each city of residence on the utility. All these dummy variables have alternative specific parameters assuming that each alternative is perceived differently by the respondents with the same current city of residence. Setting the current alternative and Taipei City as a base case, for alternatives of not moving but shift to SAV and moving farther from the most frequent trip destination with SAV, the significant parameters are retained with the New Taipei City $(IsNewTaipei)$, and for alternative of moving closer to the most frequent trip destination with SAV, the significant parameters are retained with the Taoyuan City $(IsTaoyuan)$. The final model specification is shown in equation 22 to 25, and the final model estimation is shown in Table 34.

$$V_{current} = \beta_{MTCtoIncome,current}\frac{MTCtoIncome_{current}}{100} + \beta_{TT,current}\frac{TT_{current}}{100} \tag{22}$$

$$V_{NoMoveSAVnoShare} = ASC_{NoMoveSAVnoShare} + \beta_{MTCtoIncome,NoMoveSAVnoShare}\frac{MTCtoIncome_{NoMoveSAVnoShare}}{100} + \beta_{isnewtaipei,NoMoveSAVnoShare}IsNewTaipei \tag{23}$$

$$V_{MoveFartherSAVnoShare} = ASC_{MoveFartherSAVnoShare} + \beta_{MTCtoIncome,MoveFartherSAVnoShare}\frac{MTCtoIncome_{MoveFartherSAVnoShare}}{100} + \beta_{TT,MoveFartherSAVnoShare}\frac{TT_{MoveFartherSAVnoShare}}{100} + \beta_{isnewtaipei,MoveFartherSAVnoShare}IsNewTaipei \tag{24}$$

$$V_{MoveCloserSAVnoShare} = ASC_{MoveCloserSAVnoShare}\ \beta_{MTCtoIncome,MoveCloserSAVnoShare}\frac{MTCtoIncome_{MoveCloserSAVnoShare}}{100} + \beta_{TT,MoveCloserSAVnoShare}\frac{TT_{MoveCloserSAVnoShare}}{100} + \beta_{istaoyuan,MoveCloserSAVnoShare}IsTaoyuan \tag{25}$$

Note: The alternative-specific constant of current alternative is set as a base case, parameters of current alternatives, including four current cities of residence from $IsTaipei$ to $IsTaoyuan$. Moreover, all parameters of $IsTaipei$ are set as a base case relative to other cities.

Table 34 Estimation of the residential location choice model with the introduction of SAV without ride-sharing

Alternative-specific constant	Coefficient (t-test)
$ASC_{NoMoveSAVnoShare}$	-2.45 (-17.9)***
$ASC_{MoveFartherSAVnoShare}$	-2.67 (-11.2)***
$ASC_{MoveCloserSAVnoShare}$	-2.57 (-13)***
Ratio of monthly travel cost to monthly household income	
$\beta_{MTCtoIncome,current}$	-0.119 (-6.29)***
$\beta_{MTCtoIncome,NoMoveSAVnoShare}$	-0.059 (-4.06)***
$\beta_{MTCtoIncome,MoveFartherSAVnoShare}$	-0.058 (-2.33)**
$\beta_{MTCtoIncome,MoveCloserSAVnoShare}$	-0.04 (-3.2)***
Travel time	
$\beta_{TT,current}$	-1.73 (-6.73)***
$\beta_{TT,MoveFartherSAVnoShare}$	-2.71 (-4.69)***
$\beta_{TT,MoveCloserSAVnoShare}$	-2.3 (-2.2)**
Current city of residence	
$\beta_{isnewtaipei,NoMoveSAVnoShare}$	-0.791 (-4.65)***
$\beta_{isnewtaipei,MoveFartherSAVnoShare}$	0.744 (3.22)***
$\beta_{istaoyuan,MoveCloserSAVnoShare}$	0.657 (3.64)***
Initial log likelihood: -3182 Final log likelihood: -1752 Rho-square: 0.45	

Note: Significance is marked by * (p-value < 0.05), ** (p-value < 0.01), and *** (p-value < 0.005)

For the interpretation of the final residential location choice model with the introduction of SAV without ride-sharing shown in Table 34. Regarding alternative-specific constants, compared to the current alternative, the constants of remaining three residential location alternatives are within -3, which is the small magnitude that probably contain less and similar unobserved attributes, taste variation or measurement error.

Parameters of property cost in all four alternatives are insignificant, which means that property cost is not the influential factor of residential location choice with the introduction of SAV-without ride-sharing. Regarding the ratio of monthly travel cost to monthly household income, all alternatives have negative coefficients, and the current alternative has the minimum coefficient implying that with the higher amount of monthly travel cost per monthly household income, the current alternative is less likely to be chosen. In other words, with the lager ratio indicating people who spend more travel cost with the same monthly income or spend same travel cost but has a lower income, people would like to make a change either shift to SAV without moving, moving farther or closer from their most frequent trip destination with SAVs.

Regarding travel time, coefficients of travel time are all negative except the alternative of the shift to SAV without moving, which is insignificant. Among the three parameters of travel time, an alternative of moving farther from their most frequent trip destination has the minimum coefficient implying this alternative is the most time-sensitive alternative.

Regarding the current city of residence, compared to the current alternative and the Taipei City, residents in New Taipei City are less likely to shift to SAV without moving while more likely to move farther from their most frequent trip destination with SAV. It is probably because there will plan to be more new residential areas in the outskirt of New Taipei City in future decades thus people might be willing to move farther for the cheaper place of residence with SAV for commuting. Besides, residents in Taoyuan City are more likely to move closer to their most frequent trip destination with SAV. It is probably because Taoyuan

City has relatively larger territory than Taipei and New Taipei City, the public transit system is not well developed, and the house price is the relatively lower thus people there would likely to move closer with more convenient transport mode, namely SAV. At last, all four parameters of Keelung City are insignificant due to the lack of sample size and variety.

5.3.2 Model with introduction of SAV with ride-sharing

For the residential location choice with the introduction of SAV with ride-sharing, the procedure of developing the model is as same as previous one. The base model is built with alternative specific constants (ASC), which the current alternative is set as a base case, property cost (PC), the ratio of monthly travel cost to monthly household income $(MTCtoIncome)$, and travel time (TT). All variables above have alternative specific parameters that this research assumes they are perceived differently in each alternative. Insignificant parameters including all property cost except the alternative of moving farther from their most frequent trip destination with SAVs and the ratio of monthly travel cost to the monthly household income of moving farther from and closer to their most frequent trip destination with SAVs are withdrawn. All four parameters of travel time alternatives are significant and retained.

Secondly, four dummy variables of cities city of residence are added to identify the effect of each city of residence on the utility. All these dummy variables have alternative specific parameters assuming that each alternative is perceived differently by the respondents with the same city of residence. The current alternative and Taipei City are set as a base case. For alternatives of not moving but shift to SAVs and moving farther from the most frequent trip destination with SAVs, the significant parameters are retained with the New Taipei City $(IsNewTaipei)$. For an alternative of moving closer to the most frequent trip destination with SAVs, the significant parameters are retained with the Taoyuan City $(IsTaoyuan)$. The final model specification is shown in equation 26 to 29, and the final model estimation is shown in Table 35.

$$V_{current} = \beta_{MTCtoIncome,current}\frac{MTCtoIncome_{current}}{100} + \beta_{TT,current}\frac{TT_{current}}{100} \quad (26)$$

$$\begin{aligned} V_{NoMoveSAVshare} = {} & ASC_{NoMoveSAVshare} + \\ & \beta_{MTCtoIncome,NoMoveSAVshare}\frac{MTCtoIncome_{NoMoveSAVshare}}{100} + \\ & \beta_{TT,NoMoveSAVshare}\frac{TT_{NoMoveSAVshare}}{100} + \\ & \beta_{isnewtaipei,NoMoveSAVshare} IsNewTaipei \end{aligned} \quad (27)$$

$$\begin{aligned} V_{MoveFartherSAVshare} = {} & ASC_{MoveFartherSAVshare} + \\ & \beta_{PC,MoveFartherSAVshare}\frac{PC_{MoveFartherSAVshare}}{100{,}000} + \\ & \beta_{TT,MoveFartherSAVshare}\frac{TT_{MoveFartherSAVshare}}{100} + \\ & \beta_{isnewtaipei,MoveFartherSAVshare} IsNewTaipei \end{aligned} \quad (28)$$

$$\begin{aligned} V_{MoveCloserSAVshare} = {} & ASC_{MoveCloserSAVshare} + \\ & \beta_{TT,MoveCloserSAVshare}\frac{TT_{MoveCloserSAVshare}}{100} + \\ & \beta_{istaoyuan,MoveCloserSAVshare} IsTaoyuan \end{aligned} \quad (29)$$

Note: The alternative-specific constant of current alternative is set as a base case, parameters of current alternatives, including four current cities of residence from $IsTaipei$ to $IsTaoyuan$. Moreover, all parameters of $IsTaipei$ are set as a base case relative to other cities.

Table 35 Estimation of the residential location choice model with the introduction of SAV without ride-sharing

Alternative-specific constant	Coefficient (t-test)
$ASC_{NoMoveSAVshare}$	-1.66 (-12.4)***
$ASC_{MoveFartherSAVshare}$	-2.7 (-10.8)***
$ASC_{MoveCloserSAVshare}$	-1.79 (-9.99)***
Property cost	
$\beta_{PC,MoveFartherSAVshare}$	-0.00425 (-2.72)**
Ratio of monthly travel cost to monthly household income	
$\beta_{MTCtoIncome,current}$	-0.0762 (-5.52)***
$\beta_{MTCtoIncome,NoMoveSAVshare}$	-0.195 (-5.62)***
Travel time	
$\beta_{TT,current}$	-2.46 (-8.74)***
$\beta_{TT,NoMoveSAVshare}$	-0.697 (-2.25)*
$\beta_{TT,MoveFartherSAVshare}$	-1.81 (-5.12)***
$\beta_{TT,MoveCloserSAVshare}$	-5.08 (-5.73)***
Current city of residence	
$\beta_{isnewtaipei,NoMoveSAVshare}$	-0.66 (-4.55)***
$\beta_{isnewtaipei,MoveFartherSAVshare}$	0.734 (3.7)***
$\beta_{istaoyuan,MoveCloserSAVshare}$	0.466 (2.69)**
Initial log likelihood: -3182 Final log likelihood: -2143 Rho-square: 0.327	

Note: Significance is marked by * (p-value < 0.05), ** (p-value < 0.01), and *** (p-value < 0.005).

For the interpretation of the final residential location choice model with the introduction of SAV with ride-sharing shown in Table 35. Regarding alternative-specific constants, compared to the current alternative, the constants of remaining three residential location alternatives are within -2.7, which is a small magnitude that probably contains less unobserved attributes, taste variation or measurement error.

Parameters of property cost of the alternative of moving farther from their most frequent trip destination with SAVs are significant which means people who has own property or the higher housing and rental cost will reduce the willingness to move farther with SAVs. Regarding the ratio of monthly travel cost to monthly household income, alternatives of current and without moving but the shift to SAVs are significant and have negative coefficients. Besides, the current alternative has the maximum coefficient implying that with the same amount of monthly travel cost increased per monthly household income, people are more likely to remain their residential location without shifting to SAVs. This result is opposite to the previous model that the current alternative has the minimum coefficient. This trend is because it is more cost-sensitive when people choose between current mode and SAV with ride-sharing than choose between current mode and SAV without ride-sharing since monthly travel cost of SAV with ride-sharing is much cheaper than SAV without ride-sharing.

Regarding travel time, the coefficients of travel time are all negative. Among the four parameters of travel time, an alternative of moving closer to their most frequent trip destination has the minimum coefficient implying people with longer travel time will be the least likely to move closer to their most frequent trip destination. It is probably because they are not able to afford the higher property cost, while they can afford slightly higher travel cost with less property cost by moving farther.

Regarding the current city of residence, compared to the current alternative and the Taipei city, people live in New Taipei City are less likely to shift to SAV without moving while more likely to move farther from their most frequent trip destination with SAV. It is probably because there will plan to be more new residential areas in the outskirt of New Taipei City in future decades; thus people might be willing to move farther for a cheaper house with SAVs for commuting. Besides, residents in Taoyuan City are more likely to move closer to their most frequent trip destination with SAVs. It is probably because Taoyuan City has relatively larger territory than Taipai and New Taipei City, the public transit system is not well developed, and the house price is the relatively lower thus people there would likely to move closer with more convenient transport mode, namely SAV. Generally, the coefficients of the parameters above are almost as same as the previous model which implying that the cities of residence have almost the same influence on residential location choice with SAV with- and without ride-sharing respectively. At last, all four parameters of Keelung City are insignificant due to the lack of sample size and variety.

Overall, the two residential location model have a similar trend in terms of the estimated parameters and the sign of each coefficient. In contrast, people have a slightly different perception of the ratio of monthly travel cost to monthly household income and travel time.

Chapter 6. Case Study

In this chapter, the two mode choice models and two residential location choice models will be applied to simulate the potential modal shift and residential location choice in the Taipei metropolitan area with survey data of this research and national household travel survey data. Firstly, the way of processing national household travel survey data to extrapolate the attributes that fit the two mode choice models will be described. Secondly, the application of the mode choice models with both survey data of this research and national household travel data, and residential location choice models with survey data of this research will be elaborated.

6.1 National household travel survey data processing

The national household travel survey data was conducted in the entire area of Taiwan in 2016. It mainly consists of respondents' trip characteristics of one day before the survey in weekday and socio-demographic characteristics. The procedure of processing the national household travel data is shown in Figure 24 that will be elaborated in the following paragraph.

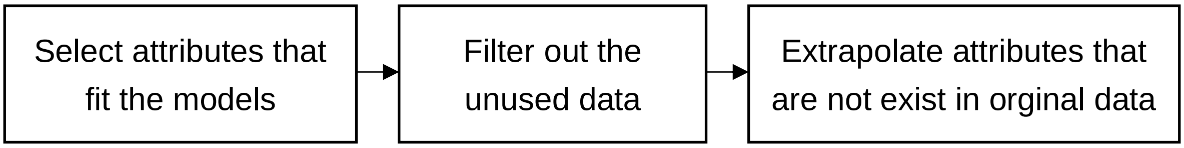

Figure 24 Procedure of national household travel survey data processing

Firstly, the attributes which can be applied and be extrapolated to models are retained, which is shown in Table 36.

Table 36 Retained attributes of national household travel survey data (Taiwan Ministry of Transportation, 2016)

Travel attributes	Socio-demographic attributes
General Travel characteristic	Age
Most frequently used mode	Gender
Work or school location	Education
Yesterday's trips	Occupation
Whether went out yesterday	Residential location
Trip purposes	
1st used mode and travel time each trip	
2nd used mode and travel time each trip	
3rd used mode and travel time each trip	
4th used mode and travel time each trip	

Note: Work, school, and residential location include cities and district level

Secondly, the unused data are filtered out so that there are initially 4,855 respondents in the Taipei metropolitan area. After filtering out the respondents of people who did not go out yesterday, and the modes used yesterday did not include the most frequently used mode. There are 3,392 respondents left for further data processing.

Thirdly, the attributes that do not exist in original data will be extrapolated in order to fit the models. For deriving the attributes of the most frequent trip purpose, the trip of going to work or school is presumably selected as the most frequent trip. If there are no trip purposes for work or school, then the respondents' first conducted trip yesterday is presumably selected as the most frequent trip. For deriving the most frequently used transport mode, the mode hierarchy shown in Table 37 is used to define which mode is the primary mode if respondents used multiple modes in that specific trip. After defining the primary mode, the travel time of that mode is defined as in-vehicle time, while travel time of other mode is defined as out-of-vehicle time. Besides, if there are missing value such as people who took a bus and metro, but only travel time of metro is available, the out-of-vehicle time is defined by the average of out-of-vehicle time of bus in the survey data of this research.

Table 37 Mode hierarchy for processing national household travel data

Mode hierarchy
Train
Taxi
Private car
Scooter
Metro
Bus
Bike
Walk

After defining the primary mode, in- and out-of-vehicle travel time. Since travel cost is not provided, thus the travel cost is extrapolated by the survey data of this research in terms of fuel cost and parking cost. The derivation of fare cost of public transit and the public bike is as same as the procedure of designing the survey of this research shown in Table 10. Therefore, the in- and out-of-vehicle generalized cost are extrapolated by the value of time of 3.93 and 7.86 NTD per minute, respectively also from Yu (2019).

Finally, for the socio-demographic attributes, the ownership of private car and scooter are extrapolated by those who used one of the two modes above as primary mode or used yesterday will be assigned one ownership. Afterwards, the ownership is randomly assigned by either one or zero with a probability of whether having the ownership that derived by survey data in this research according to different cities. Furthermore, the monthly household income is extrapolated by the monthly household income according to each occupation and age group with normal distribution with the data from Taiwan Department of Accounting (2019) and the survey data of this research for some unincluded occupations. At last, the weights are derived with census data in order to match the realistic percentage of gender and age groups. Ultimately, the processed national household travel survey data will be applied in mode choice models in the next section.

6.2 Simulation of mode choice

In this section, firstly, the exploration of the potential modal split by applying SP-RP combined mode choice model in each scenario are elaborated. Secondly, the shift of each mode to SAVs by applying SP mode choice model in each scenario are elaborated. Both mode choice models used survey data of this research and national household travel survey data to simulate the results.

6.2.1 Modal split in SAV scenarios

The RP-SP combined mode choice model was applied to predict the potential modal shift in each scenario of both SAV alternatives. The modal split result applied by calibrated and uncalibrated models shown in Table 38, were compared in order to evaluate the plausibility and realness of the calibrated model. It is worth noting that the official modal split of the Taipei metropolitan area in the first row of national observation is calculated by the percentage of the most frequently used transport modes which were asked in the survey instead of the mode used at yesterday. It is because most of the trip characteristics are recorded for respondents' trips that were one day before the survey. Therefore, although using the same dataset, the modal split of the data used in this research is different from the official modal split shown in Table 3.

Table 38 also shows that uncalibrated and calibrated models have the same trend of changing the percentage of modal shift from observation to scenario 1 (e.g. both models' changes of the modal split of the scooter are around -20 %). Moreover, the share of both SAV alternatives in scenario 1 reduces almost 9% after calibration. It is because the share of the scooter is under-represented before calibration and since scooter users are more reluctant to shift to SAV alternatives compares to other modes. Therefore, the overall mode shares of both SAV alternatives are reduced. Generally, the entire modal split using the calibrated model is closer to realistic context; thus, for the following analysis of modal split will base on the calibrated RP-SP combined model.

Table 38 Modal split by applying RP-SP combined model with survey data before and after calibration in scenario 1 (Taiwan Ministry of Transportation, 2016)

		Private mode		Public transit				Active mode		SAV	
Data / Model calibration	Observation / Scenario1	Private car	Scooter	Train	Taxi	Metro	Bus	Bike	Walk	SAV No Share	SAV Share
HH travel survey data	National Observation	18%	35%	2.5%	4%	12%	14%	3%	10%		
Survey data Uncalibrated	Observation	34.6%	16.7%	1.7%	1%	26.1%	13.4%	3.1%	3.4%		
	Scenario 1	19.5%	12.9%	1.5%	0.6%	14.8%	7.5%	2.3%	2.3%	11.5%	27.1%
Survey data Calibrated	Observation	23.4%	35%	1.7%	4%	12%	11.1%	3%	10%		
	Scenario 1	15.3%	28%	1.3%	2.3%	6.3%	5.7%	1.7%	9.6%	8.9%	20.8%

Regarding potential modal split after the introduction of the SAVs in four scenarios shown in Table 39. Except for the private car and walk, the mode share and the trend of other modes are relatively close between applying the model with survey data and national household travel survey data. The share of the private car is under-represented, and the share of the walk is over-represented in national household travel survey data. There are approximately 5% decrease in the share of SAV without ride-sharing and 8% decrease in the share of SAV with ride-sharing if the SAV fare rate and waiting time are doubled (i.e., change from scenario 1 to 4). The modal split of scenario 2 and 3 are almost identical, which means the sensitivity toward doubling the price and waiting time is almost the same.

Overall, in all scenarios, the share of SAV with ride-sharing has more than twice as much as the share of SAV without ride-sharing. Among the conventional modes, people who use a private car, taxi, metro, bus and bike have a relatively larger modal shift. In contrast, people who use a scooter, train, and walk have a relatively lower modal shift. This trend indicated that the private car users might more likely to shift to SAVs relative to the scooter as this research expected previously. Unexpectedly, there is also the larger shift of metro and bus to both SAV alternatives. However, there might be some internal shift among conventional modes in RP-SP combined mode choice models thus the further analysis of the modal shift from each conventional mode to both SAV alternatives was conducted and elaborated in the next subsection.

Table 39 Modal split by applying calibrated RP-SP combined mode choice model with survey and national household travel survey data (HH travel data) (Taiwan Ministry of Transportation, 2016)

		Private mode		Public transit				Active mode		SAV	
Data	Scenario	Private car	Scooter	Train	Taxi	Metro	Bus	Bike	Walk	SAV No Share	SAV Share
Survey data	Observation	23.4%	35%	1.7%	4%	12%	11.1%	3%	10%		
	Scenario 1	15.3%	28%	1.3%	2.3%	6.3%	5.7%	1.7%	9.6%	8.9%	20.8%
	Scenario 2	17.7%	30%	1.5%	2.9%	7.6%	6.9%	1.8%	9.6%	5.4%	16.5%
	Scenario 3	17.3%	30%	1.4%	2.7%	7.4%	6.8%	1.9%	9.7%	6%	16.9%
	Scenario 4	19.2%	31.5%	1.5%	3.1%	8.6%	7.9%	2.1%	9.7%	3.5%	12.9%
HH travel survey data	Observation	11.9%	30.7%	1.1%	4.1%	10.8%	15.6%	6.9%	18.8%		
	Scenario 1	6.6%	25.4%	0.8%	2.1%	5%	6.3%	3.4%	18.1%	9.8%	22.4%
	Scenario 2	8%	26.7%	1%	2.7%	6.3%	7.9%	3.7%	18.1%	6.6%	19%
	Scenario 3	7.8%	26.9%	0.9%	2.5%	6.1%	7.8%	4%	18.3%	6.9%	18.9%
	Scenario 4	9%	27.9%	1%	3%	7.2%	9.3%	4.3%	18.3%	4.5%	15.4%

6.2.2 Modal shift from each mode to SAV alternatives

The modal shift from each conventional mode to SAVs will be analyzed with SP mode choice model, which consists of three alternatives including the current mode in use and both SAV alternatives. Firstly, Table 40 shows the modal shift from the current mode in use to both SAV alternatives by applying SP mode choice model with survey data and national household travel survey data. The modal splits are similar using both datasets in each scenario, and there are approximately 6% decrease in the share of SAV without ride-sharing and 9% decrease in the share of SAV with ride-sharing if the SAV fare rate and waiting time are doubled (i.e., change from scenario 1 to 4). The share of current mode in scenario 2 is slightly lower than scenario 3, which means that people are slightly more reluctant to change to SAVs when doubling the waiting time than doubling the price. Moreover, the share of both SAV alternatives applying RP-SP combined model in Table 39 and SP modes in Table 40 has approximately 7% difference in each scenario by using the survey data of this research. It is because the changes of the modal split after the calibration of RP-SP combined model result in the changes of the share of both SAVs alternatives.

Overall, there are expected to be approximately 21% to 38% share of both SAV alternatives. Besides, the share of SAV with ride-sharing has more than twice as much as the share of SAV without ride-sharing, which is identical to the mode share difference between both SAVs alternatives by applying RP-SP combined model.

Table 40 Modal shift changes by applying the SP mode choice model with survey and national household travel survey data (HH travel data) (Taiwan Ministry of Transportation, 2016)

Data	Scenario	Current Mode	SAV without ride-sharing	SAV with ride-sharing
Survey data	Scenario 1	62.0%	11.2%	26.7%
	Scenario 2	69.9%	7.7%	22.4%
	Scenario 3	70.7%	7.6%	21.7%
	Scenario 4	77.3%	5.1%	17.6%
HH travel survey data	Scenario 1	64.3%	11.8%	23.9%
	Scenario 2	70.8%	8.8%	20.4%
	Scenario 3	73.4%	7.7%	18.9%
	Scenario 4	78.5%	5.7%	15.8%

Secondly, the modal shift of each conventional mode to both SAV alternatives applying SP model with the survey and national household travel survey data of this research in scenario 1 and 4 are shown in Table 41. Generally, the share of both SAV alternatives for users of every conventional mode decreased if the SAV fare rate and waiting time are doubled (i.e., change from scenario 1 to 4). The users of the private car, taxi, metro, and bus are most willing to shift to SAVs, especially to mostly the SAV with ride-sharing. In contrast, the users of the scooter, train and bike are less likely to shift to SAVs.

Between the survey data and national household travel survey data, there are also different share in train, taxi and walk. For the difference in the mode share of train between two datasets, it is probably because of the relatively small sample sizes of both datasets and different ratio of high-speed train and conventional train in each dataset. For the difference in the mode share of the taxi, it is also because of the lack of sample sizes in both datasets. For the difference in modes share of walking, it is probably also because of the necessity of more the sample sizes in survey data and the existence of unobserved factors. Besides, the average walk time of the survey data in this research is over 30% less than in national household travel survey data thus result in the higher share of SAVs by using national household travel survey data. Nevertheless, the overall trends of modes above still make sense that the users of the train are more reluctant to shift to SAVs. In contrast, the users of the taxi are more willing to shift to SAVs, especially without ride-sharing, which has a similar function as a taxi, comparing to other conventional modes.

Overall, the trend of modal shift from each conventional mode to both SAV alternative shows that the users of the private car, metro, and bus are more likely to shift to SAV alternatives. Between both SAV alternatives, the mode share of SAV with ride-sharing has more than twice as much as the share of SAV without ride-sharing. It is probably because, for the users of the private car, the price halved with an only slight increase in travel time compared to their private car and SAV without ride-sharing; For the users of the metro and bus, although the travel cost of SAV with ride-sharing will be slightly higher than public transit modes above, the travel time will be significantly reduced. In contrast, for the users of scooter, train, and bike are less likely to shift to SAV alternatives. It is probably because the scooter is the relatively cheap, fast and easy-to-access mode, users of train mainly travel with long distance with relatively high speed and cheap fare price, and users of bike mainly travel with a short distance with extreme low fare.

Table 41 Modal shift from each conventional mode to both SAV alternatives by applying SP mode choice model with survey and national household travel survey data (HH travel data) in scenario 1 and 4 (Taiwan Ministry of Transportation, 2016)

		Private mode		Public transit				Active mode	
Data type	Modal shift	Private car	Scooter	Train	Taxi	Metro	Bus	Bike	Walk
Survey data	Scenario 1								
	Current	55.2%	78.7%	95.5%	66.8%	57.8%	57.7%	78.5%	65.7%
	SAV No Share	14.2%	10%	1.9%	28.4%	8.4%	11.1%	9.4%	10.5%
	SAV Share	30.6%	11.3%	2.6%	4.8%	33.8%	31.2%	12.1%	23.8%
	Scenario 4								
	Current	73.1%	89%	99.1%	80.5%	74.4%	74.4%	87.2%	75%
	SAV No Share	6.4%	4.3%	0.2%	16%	3.7%	4.8%	4.9%	6.8%
	SAV Share	20.5%	6.7%	0.6%	3.5%	21.9%	20.7%	7.9%	18.2%
HH travel survey data	Scenario 1								
	Current	52.8%	78.9%	78.3%	26.5%	65.8%	59.1%	83.5%	56.3%
	SAV No Share	14.2%	9.8%	7.7%	60%	7%	10.5%	7.2%	11.7%
	SAV Share	32.9%	11.3%	14%	13.6%	27.2%	30.4%	9.3%	32.1%
	Scenario 4								
	Current	73.4%	88.6%	89.6%	43.2%	80.8%	75.9%	90.1%	66.5%
	SAV No Share	6%	4.5%	2.7%	43.2%	2.9%	4.8%	3.8%	7.8%
	SAV Share	20.6%	6.9%	7.8%	13.6%	16.3%	19.4%	6.1%	25.7%

6.3 Simulation of residential location choice

In this section, the exploration of the potential relocation choice, relocation behavior of users of each mode, and relocation behavior of residents in each city by applying the residential location choice models with each SAV alternative will be elaborated. Only the survey data of this research was used for the model application since the data related to this topic does not exist in the accessible sources.

6.3.1 General trend of relocation behavior with both SAV alternatives

The residential location choices with the introduction of each SAV alternative in each scenario are shown in Table 42. For the introduction of the SAV without ride-sharing, nearly 90% of residents are unwilling to move in both scenarios. The difference between scenario 1 and 2 are within 2%, thus for doubling SAV fare rate and waiting time does not change the distribution of residential location. Generally, the residents are more tends to move closer to their most frequent trip destination.

For the introduction of the SAV with ride-sharing, over 80% of residents are unwilling to move in both scenarios, which are lower than relocation behavior with SAV with ride-sharing. It is probably because the travel cost of the SAV with ride-sharing is relatively lower; thus, more residents want to relocate. The difference between scenario 1 and 2 are almost similar in alternatives of not moving but shift to SAV and move farther to residents' most frequent trip destination, while there is almost 3% difference in the alternative of moving closer to respondents' most frequent trip destination. Generally, the residents are more tends to move closer to their most frequent trip destination as the same trend as SAV without ride-sharing.

Table 42 Residential location choices in scenarios of both SAV alternatives using survey data

SAV alternative	Scenarios	Current alternative	Current Location with SAVs	Move Farther with SAVs	Move Closer with SAVs
SAV without ride-sharing	Scenario 1	72.2%	13.7%	4.1%	10.0%
	Scenario 2	73.9%	14.1%	3.2%	8.7%
SAV with ride-sharing	Scenario 1	63.7%	16.5%	5.2%	14.6%
	Scenario 2	68.9%	14.2%	5.1%	11.8%

6.3.2 Relocation behavior of users of each mode

The relocation behavior of users of each mode is shown in Table 43. Generally, residents who are willing to move closer to the most frequent trip destination have more share than moving farther from the most frequent trip destination. Besides, when doubling SAV fare rate and waiting time of SAVs (i.e., change from scenario 1 to 2), the share of moving farther from and closer to their most frequent trip destination with both SAV alternatives are reduced in each mode.

The users of private car and bus are more likely to move farther from and closer to their most frequent trip destination with both SAV alternatives compare to other modes' users. In contrast, the users of the train and taxi are less likely to move farther from and closer to their most frequent trip destination with both SAV alternatives. Moreover, the users of bike and walk are more unlikely to neither change their mode nor residential location compare to other modes.

Table 43 Residential location change from each current mode to other three alternatives using survey data

		Private mode		Public transit				Active mode	
Available SAV mode	Alternative	Private vehicle	Scooter	Train	Taxi	Metro	Bus	Bike	Walk
SAV without ride-sharing	Scenario 1								
	Current	70.5%	78.5%	64.1%	72.4%	71.7%	68%	75.6%	79.2%
	Only mode shift	14.4%	9.5%	24.8%	16.8%	15%	15.2%	11.5%	7.4%
	Move farther	3.6%	4.4%	0.5%	3.1%	4.3%	4.4%	5.4%	6.6%
	Move closer	11.5%	7.6%	10.6%	7.7%	9.1%	12.4%	7.5%	6.8%
	Scenario 2								
	Current	72.2%	80.1%	65.5%	74.2%	73.6%	70.1%	76.9%	80.5%
	Only mode shift	14.8%	9.7%	25.9%	17.2%	15.4%	15.8%	11.7%	7.5%
	Move farther	2.8%	3.5%	0.4%	2.3%	3.3%	3.4%	4.7%	5.8%
	Move closer	10.2%	6.7%	8.2%	6.2%	7.7%	10.8%	6.7%	6.1%
SAV with ride-sharing	Scenario 1								
	Current	64.1%	70.7%	70.9%	68.8%	61.5%	54.5%	63.9%	71.7%
	Only mode shift	17.3%	12.9%	10.9%	13.5%	17 %	19.5%	19.7%	12.1%
	Move farther	4.3%	5.1%	1 %	4.7%	6.4%	6.5%	4.2%	4.7%
	Move closer	14.3%	11.3%	17.2%	13.0%	15.1%	19.4%	12.2%	11.6%
	Scenario 2								
	Current	69.5%	75.1%	77.0%	74.7%	67.0%	60.4%	67.4%	74.7%
	Only mode shift	14.7%	11.1%	7.8%	10.4%	14.5%	16.7%	19.1%	12.0%
	Move farther	4.2%	4.9%	1.0%	4.6%	6.3%	6.5%	4.0%	4.4%
	Move closer	11.6%	8.9%	14.2%	10.4%	12.2%	16.4%	9.5%	8.9%

6.3.3 Relocation behavior of residents' city of residence

The relocation analysis in this research is based on the assumption of moving farther from the most frequent trip destination has lower property price, and those who move closer has higher property price than the current residential location. Besides, residents whose residential location and their most frequent trip destination are in the same city and the same district have the smallest relocation range, while if the relationship of locations above is in different cities, residents have the most extensive relocation range.

Regarding the relocation behavior of the relationship between the city of residence and the city of the most frequent destination with the introduction of SAV without ride-sharing shown in Table 44. In this research, Taipei City (i.e., Taipei) is assumed to be the urbanized area, and New Taipei City (i.e., New Taipei) and Taoyuan City (i.e., Taoyuan) are assumed to be the suburban areas. However, Keelung City (i.e., Keelung) has a relatively smaller sample size; thus, it is removed from this simulation. The pairs of origin and the most frequent destination (OD) with the percentage of a total population larger than 3% are counted. Residents in Taipei who are willing to move either farther from or closer to the destination in New Taipei are categorized as suburbanization. It is because New Taipei surrounded Taipei; thus residents move farther from New Taipei are assumed to move outward from the Taipei to the opposite side of New Taipei, and residents both move closer to New Taipei are also assumed to move outward from the Taipei to get closer to their destination. For residents in New Taipei who is willing to move farther from Taipei and closer to Taoyuan are also classified as suburbanization because this is the clear trend that people move outward from the city center. In contrast, residents in New Taipei who willing to move closer to Taipei is classified as urbanization.

As the Table 44 shows, for the trend of not moving, residents in Taipei are more likely to maintain their current residential location and more likely to shift to SAV without ride-sharing without moving than residents in New Taipei and Taoyuan. For residents in New Taipei, they are the least likely to shift to SAV without ride-sharing without moving when their most frequent trip destination is in Taipei and New Taipei. However, if their most frequent trip destination is in Taoyuan, then the share of shifting to SAV without ride-sharing without moving is the highest among all OD pairs.

For the trend of moving either farther or closer, residents in Taipei are the least likely to relocate with SAV without ride-sharing, it is probably because the development of residential areas in Taipei has already saturated. In contrast, the OD pairs of New Taipei to Taoyuan and Taoyuan to Taoyuan has the highest share of moving, especially moving closer to Taoyuan. It is probably because the Taoyuan has the lowest property cost compare to Taipei and New Taipei. Furthermore, only OD pair that both located in New Taipei has the almost equal share of moving farther from and moving closer to destination. It is probably because there are many undergoing developments of new residential areas; thus, more residents are willing to move farther away from their destination due to the lower property cost.

Table 44 Relocation behavior of relation between the city of residence and the most frequent trip destination with the introduction of SAV without ride-sharing

Scenario 1			Alternatives			
Residential location	Most frequent trip destination	Percentage of total population	Current alternative	No Move with SAV	Move farther with SAV	Move closer with SAV
Taipei	Taipei	42.9%	73%	15.5%	3.7%	7.7%
	New Taipei	5.3%	71.6%	16.6%	2.1%+	9.7%+
New Taipei	Taipei City	17.8%	74.3%	9%	5.2%+	11.5%-
	New Taipei	11.5%	77.5%	7%	7.6%	7.9%
	Taoyuan	3.7%	62%	17.5%	3.6%-	16.9%+
Taoyuan	Taoyuan	12.1%	69.3%	13.8%	3.2%	13.8%

Note:

1. Only the pair of origin and destination with the percentage of total population exceed 3% are counted

2. + denotes suburbanization trend, - denotes urbanization trend

Overall, after weighting the percentage of each moving alternative in each OD pair with the percentage of the total population, the relocation trend after the introduction of the SAV without ride-sharing is shown in Figure 25. In scenario 1, there are 2.1% of the entire population in the Taipei metropolitan will across the city and move to suburban areas, namely New Taipei and Taoyuan, while 2.1% will across the city and move to the urban area, namely Taipei. Therefore, the people who move outward from and inward to the city center are the same. In scenario 2, there is also the same trend that suburbanization and urbanization have almost the same share with a relatively lower percentage.

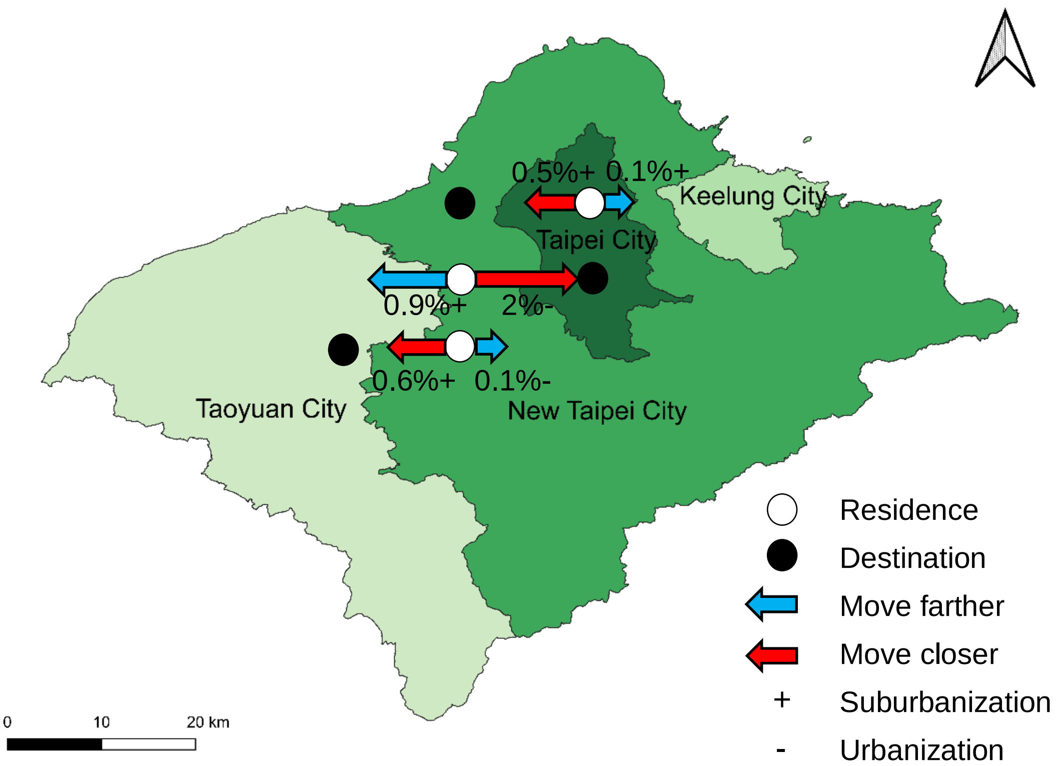

Figure 25 Relocation trend with SAV without ride-sharing in scenario 1

Regarding the relocation behavior of relationship between the city of residence and the city of the most frequent destination with the introduction of SAV with ride-sharing shown in Table 45, there are fewer residents choose to maintain their residential location and transport mode than with the introduction of the SAV without ride-sharing. Therefore, there is more share of the other three alternatives. It is probably because of the significant reduction in travel cost that is shared with another passenger, which makes people are more willing to shift to SAV and also change their residential locations. The distribution of each OD pairs in three moving alternatives with SAV with ride-sharing is identical to the one with the SAV without ride-sharing, while the percentage is increased.

Table 45 Relocation behavior of relation between the city of residence and the most frequent trip destination with the introduction of SAV with ride-sharing

Scenario 1			Alternatives			
Residential location	Most frequent trip destination	Percentage of total population	Current	No Move with SAV	Move farther with SAV	Move closer with SAV
Taipei	Taipei	42.9%	65.1%	19.6%	3.9%	11.4%
	New Taipei	5.3%	61.9%	19.1%	2.9%+	16.1%+
New Taipei	Taipei	17.8%	61.9%	11.1%	8.2%+	18.8%-
	New Taipei	11.5%	69.9%	9.7%	9.2%	11.2%
	Taoyuan	3.7%	58.8%	11.8%	7.2%-	22.3%+
Taoyuan	Taoyuan	12.1%	63.7%	16.9%	3.8%	15.6%

Note:

1. Only the pair of origin and destination with the percentage of total population exceed 3% are counted
2. + denotes suburbanization trend, - denotes urbanization trend

Overall, after weighting the percentage of each moving alternative in each OD pair with the percentage of the total population, the relocation trend after the introduction of the SAV with ride-sharing is shown in Figure 26. In scenario 1, there are 3.4% of the entire population in the Taipei metropolitan will across the city and move to suburban area, namely New Taipei and Taoyuan, while 3.6% will across the city and move to the urban area, namely Taipei. Therefore, the people who move outward from and inward to the city center are quite similar. In scenario 2, there is also the same trend that suburbanization and urbanization have a similar share with a relatively lower percentage. Therefore, there is overall no large relocation in the Taipei metropolitan area with the introduction of both SAV alternatives. It is worth noting that this research only considered the inter-city trip as potential relocation trend.

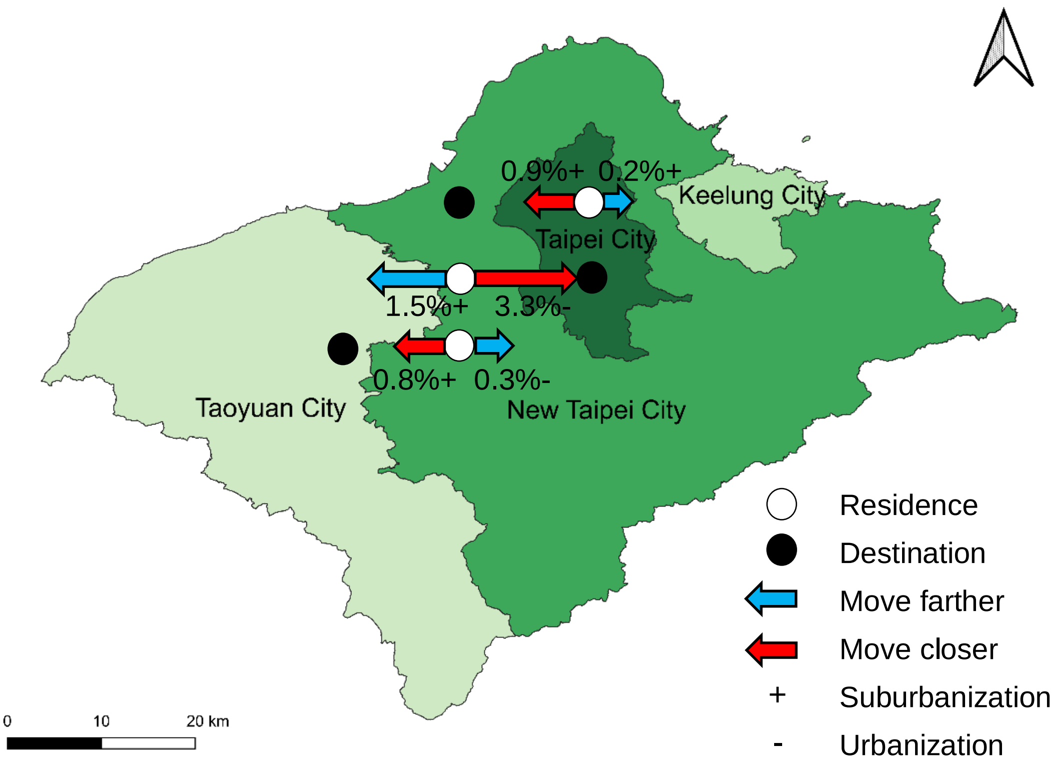

Figure 26 Relocation trend with SAV without ride-sharing in scenario 1

Chapter 7. Discussion and Conclusion

In the last chapter, firstly, the discussion on the research findings on mode choice and residential location choice in terms of model estimation and case study, and the comparison of these findings to other research findings will be elaborated. Secondly, the conclusion of this research will be summarized. Thirdly, the limitation of this research will be explained. At last, the recommendation for further research about this research topic will be described.

7.1 Main findings on mode choice

One of the research questions: How will the SAVs affect the choice of transport modes in the case of the Taipei metropolitan area, Taiwan? The main findings will be elaborated in this section.

7.1.1 Model estimation

For the mode choice preference with the introduction of both SAV alternatives in both RP-SP combined model and SP model, both in-vehicle and out-of-vehicle generalized cost of SAVs negatively affects the willingness to choose both SAV alternatives which is the expected outcome. Among them, the SAV without ride-sharing is more sensitive to waiting time which has the same trend as Krueger et al. (2016).

Both models also show that people from age group 30 to 50 are less likely to use the SAV without ride-sharing than people from age group 15 to 30, while people from age group above 50 are more likely to use the SAV with ride-sharing than people from age group 15 to 30. These results indicate that although people from age group above 50 have the lowest acceptance rate of both AV and SAV before the introduction of the characteristics of SAV in the survey, there was a higher percentage of people in the age above 50 who are not aware of SAV chose SAV with ride-sharing. Generally, the youngest age group are most likely to use SAV without ride-sharing which is identical to other research (Krueger et al., 2016; Haboucha et al., 2017; Zhou et al., 2020). However, the oldest age group are most likely to use SAV with ride-sharing, which is contrary to the result of previous research above. It is probably because the different sets of age standard of older people or different model estimation process, but it is most likely the reason that the older people in Taiwan are probably more likely to adopt the new technology since there are almost 72% of people above age 55 have a smartphone with the internet that is much higher than the world average (TWNIC, 2019).

For the SP model, the male is more likely to choose both SAV alternatives than the female, which is consistent with Zhou et al. (2020) and Haboucha et al. (2017). People with higher income are more likely to choose both SAV alternatives, especially the SAV without ride-sharing. It is because they might prefer relatively faster alternative and does not want to share the vehicle with other passengers, though it is relatively more expensive than SAV with ride-sharing. The result above is also consistent with Zhou et al. (2020). For the potential modal shift from the current mode in use to both SAV alternatives, private car users are most likely to shift to both SAV alternatives probably since most of the private car users are more able to afford SAVs than other modes users which have relatively low travel cost. This result above is consistent with Krueger et al. (2016). In contrast, the users of the bike are more unlikely to use both SAV alternatives probably since the bike is the cheapest alternatives among public transit that result in the lack of affordability of both SAV alternatives. Overall, the trend of the modal shift is almost identical to the expected outcome when designing the survey.

7.1.2 Case study

After applying the survey data and national household travel survey data to both mode choice model for the case study, regarding the modal split, the share of the private car is around 15% to 19%, the scooter is around 25% to 30%, the train is around 1%, taxi is around 2% to 3%, the bus is around 6% to 9%, the bike is around 2% to 4%, the walk is around 9.5%, SAV without ride-sharing is around 4% to 10%, and SAV with ride-sharing is around 13% to 22% in four scenarios with the removal of the modal split of under- and over-estimated modes in national household travel survey data.

For the modal shift from each mode to both SAV alternatives using both datasets, 22% to 38% of people will likely to shift to both SAV alternatives, and among them, 5% to 12% shift to SAV without ride-sharing and 16% to 26% shift to SAV with ride-sharing in four scenarios. From conventional modes, generally, all modes users prefer to shift to SAV with ride-sharing more than SAV without ride-sharing except taxi users. Users of the private car have the most shift to both SAV alternatives with around 27% to 47%, the users of metro and bus also have higher shift to both SAV alternatives which are around 19% to 42% and 24% to 42% respectively in four scenarios. Besides, people who use taxi and walk also have larger shift to both SAV alternatives, although with a considerable variation of percentage between both datasets due to the insufficient sample sizes and unobserved factors. In contrast, the users of scooter and bike have the least shift to both SAV alternatives with around 11% to 21% and 10% to 22% respectively in four scenarios. Besides, the train users also have less shift to both SAV alternatives with a considerable variation of percentage between both datasets due to the insufficient sample sizes.

Overall, the trend of modal shift is mostly consistent with the expectation, while the shift from public transit users is more than expected. Besides, it is also found that trying several different ways to derive the nonexistent attributes of national household travel survey data and collect more sample sizes will increasingly improve the accuracy of the results.

7.2 Main findings on residential location choice

For another research question: How will the SAVs affect the choice of residential location in the case of the Taipei metropolitan area, Taiwan? The main findings will be elaborated in this section.

7.2.1 Model estimation

For the residential choice perception with the introduction of both SAV alternatives in two SP models, both ratios of monthly travel cost to monthly household income and travel time negatively affect the willingness to choose each relocation alternative with both SAV alternatives which is the expected outcome and consistent with Zhang & Guhathakurta (2018).

In both SP models for both SAV alternatives, people whose monthly travel cost account for a higher percentange in their monthly household income are less likely to maintain their current residential location and mode in use, and more likely to move closer to their most frequent trip destination with the introduction of SAV without ride-sharing. However, with the introduction of SAV with ride-sharing, people are more likely to maintain their current residential location and mode in use, and less likely to shift to SAVs without moving. It is probably because it is more cost-sensitive when people choose between current mode and SAV with ride-sharing than choose between current mode and SAV without ride-sharing since monthly travel cost of SAV with ride-sharing is much lower than SAV without ride-sharing.

For the single travel time, people who have longer travel time are less likely to relocate with the introduction of SAV without ride-sharing. However, with the introduction of SAV with ride-sharing, people are more likely to move farther and less likely to move closer. It is probably because people who travel longer time are not willing to change either their residential location and mode due to the relatively higher cost of SAV without ride-sharing. However, they can afford slightly higher travel cost with SAV with ride-sharing with lower property cost by moving farther.

Regarding the current city of residence, both SP models have a similar trend. Comparing to the current alternative and the Taipei City, residents in New Taipei City are more likely to move farther from their most frequent trip destination with SAVs. It is probably because there will be more new residential areas in the outskirt of New Taipei City in future; thus, people might be willing to move farther for the cheaper place of residence with SAV for commuting. Besides, residents in Taoyuan City are more likely to move closer to their most frequent trip destination with SAVs. It is probably because Taoyuan City has relatively larger territory, the public transit system is not well developed, and the house price is the relatively lower thus people there would likely to move closer with more convenient transport mode like SAV.

7.2.2 Case study

After applying the survey data to residential location choice models for the case study, with the introduction of the SAV without ride-sharing, over 70% of residents want to maintain their current residential location and mode in use, which is around 3% to 10% higher than with the introduction of SAV with ride-sharing in both two scenarios. It is probably because the travel cost of the SAV with ride-sharing is relatively lower; thus, more residents are likely to relocate. For either moving farther from or closer to the most frequent trip destination, the residents are more tends to move closer with both SAV alternatives with the share around 10% to 15% than move farther with the share around 3% to 5%.

For the relocation behavior of users of each mode, generally, all mode users tend to move closer to their most frequent trip destination. The users of private car and bus are the most likely to relocate with both SAV alternatives with the share around 13% to 19% and 14% to 26% respectively. However, the users of train and taxi are less likely to relocate with both SAV alternatives with the share around 9% to 18% for both modes. Moreover, the users of bike and walk are more prefer to maintain their residential location and mode in use.

For the relocation behavior of relationship between the city of residence and the city of the most frequent destination, with the introduction of the SAV without ride-sharing, there are totally up to 2.1% of the entire population will move to the suburban area where are New Taipei and Taoyuan, while also up to 2.1% will move to the urban area, where is Taipei. With the introduction of the SAV with ride-sharing, as the same trend as SAV without ride-sharing, there are totally up to 3.4% of the entire population will move to the suburban area, while also up to 3.6% will move to the urban area. The result has a similar but smaller relocation trend to Bansal et al. (2016). Therefore, there is overall no big relocation trend with the introduction of both SAV alternatives. Although this result only considered the inter-city trip as potential relocation trend and did not explore the complex relocation behavior of each socio-demographic characteristics, this result has a similar trend with Carrese et al. (2019) that residents in the city center are more likely to move to the suburban area than residents who live between the city center and suburban area.

7.3 Conclusion

At the final section of this research, the overall conclusion, research limitation, and potential future research will be described.

7.3.1 Overall conclusion

This research found that for both mode choice and residential location choice, SAV fare rate and waiting time are the significant attribute affecting people's willingness to shift to both SAV alternatives and relocation. For the mode choice behavior, young cohorts between age 15 to 30 are most likely to use SAV without ride-sharing, the old cohorts above age 50 are most likely to use SAV with ride-sharing. Male with the higher income is more likely to choose both SAV alternatives, especially the SAV without ride-sharing. Private car users are most likely to shift to both SAV alternatives, while the users of scooter and bike have the least shift to both SAV alternatives. Overall, there will be a 5% to 12% shift to SAV without ride-sharing and 16% to 26% shift to SAV with ride-sharing in four scenarios.

For the residential location choice behavior, with the introduction of SAV without ride-sharing, people with a lower ratio of monthly travel cost to their monthly household income and with shorter travel time are more likely to relocate, especially moving closer to their most frequent trip destination. With the introduction of SAV with ride-sharing, people with a higher ratio of monthly travel cost to their monthly household income and with longer travel time are more likely to relocate especially moving farther from their most frequent trip destination. Residents in New Taipei City are more likely to move farther from their most frequent trip destination with both SAV alternatives, and residents in Taoyuan City are more likely to move closer to their most frequent trip destination with both SAV alternatives. Overall, there will be 2.1% to 3.4% of the entire population will relocate to the suburban area, and 2.1% to 3.6% of the population will relocate to the urban area.

For research findings in this research that compare to other research, most of the research uses the personalized attribute value to design the stated mode choice experiments (Krueger et al., 2016; Haboucha et al., 2017; Zhou et al., 2020), as this research did and have similar trends except for the attribute of age. Therefore, it can be assumed that the choice experiments with personalized attributes can demonstrate the respondents' realistic situation and thus have more realistic findings on mode choice and residential location behaviors.

7.3.2 Limitation and improvement

There are several limitations in this research in terms of data collection, data processing, design of stated choice experiments, and model estimation. For the data collection, there is a lack of sample sizes in Keelung City and modes' users of taxi and train. It is because the survey was distributed online so that it is hard to averagely obtain the responses from each geographical area and users of each mode. Besides, collecting data online might exist the sample bias since those respondents are more tend to use technological device which might prefer to accept SAV. All of the limitations above can be improved by distributing the survey locally to residents in each city, users of each mode, and people with various socio-demographic characteristics to control the percentage of sample sizes to sufficient amount and percentage to enhance more credibility of data.

For the data processing, some attributes' derivation from the national household travel survey data used in case study to simulate the mode choice behavior is based on many assumptions such as the primary mode in use, out-of-vehicle time, travel cost, which might affect the result of model application. Therefore, trying another way of processing data or obtaining data with accurate and specific attributes can improve the accuracy of the model application.

For the design of stated choice experiments, generally, the respondent's understanding of the SAV scenarios is limited with the short introduction of SAV characteristics. The visualization, such as introduction video can be added in order to make respondents have a more precise and more consistent understanding of SAVs. For the attributes in the stated mode choice experiments, the fuel cost of private car and scooter which is part of the attribute of travel cost shown to the respondents might have some bias since it is derived by respondents' travel distance. Besides, some private car and scooter users are not aware of their fuel cost. Therefore, the necessity of including fuel cost in the stated choice experiment can be further estimated.

For the design of stated residential location choice experiments, both SAV alternatives are separated in each choice experiments since there will be too many alternatives if both SAV alternatives are combined in the same choice experiment with each SAV alternative has three relocation alternatives. Besides, the relocation analysis in this research is based on the assumption of moving farther from the most frequent trip destination has lower property price, and those who move closer have to spend higher property price than the current residential location. It might not reveal the reality since some residents in the city center has their workplace in the suburban area, thus moving closer to the workplace will reduce the property cost. For analyzing the trend of urbanization and suburbanization, this research only considered the inter-city trip as potential relocation trend. Therefore overall, more detailed location and property price of each area should be included, and take the intra-city trips into account in order to have a more detailed relocation trend.

For the model estimation, since there are overall more than 30 attributes, not all of them, especially the socio-demographic attributes, were involved in the modes due to the time limitation. Therefore, the model estimation with all attributes can explain more behavioral characteristics after the introduction of SAVs. For the RP-SP combined mode choice model, the model should include more attributes which are unobserved factors so that the percentage of modal shift from each mode to SAVs can be close to the result of the SP mode choice model.

7.3.3 Future research

Apart from the improvements of data collection, data processing, methodology, and design of stated choice experiments based on the previous subsections, the future research of this research can be extended by adding attitudinal attributes (i.e., latent attributes) which indicate the respondents' attitude toward SAV such as safety, comfort, environmental-friendliness to models in order to get more insight on how the perception of respondents affect the mode choice as well as residential location choice.

Furthermore, the extended topics such as how will the SAVs affect the residents in the rural area in Taiwan, how will the traffic change with the introduction of SAVs in the urban and suburban context, what will be the co-opetition among the conventional modes, SAVs, private AVs, and autonomous public transit can be explored to build a complete analysis of transportation system with the introduction of autonomous mobility for the preparation of the future autonomous era.

At last, the transportation policy white paper of Taiwan enacted by the (Taiwan Ministry of Transportation, 2019) indicates that there will be more dedication to explore autonomous mobility in terms of transportation, economy, sustainability, and policy. Therefore, the impacts of autonomous mobility on entire transportation systems and society will be the key issues to explore for the future transportation in Taiwan.

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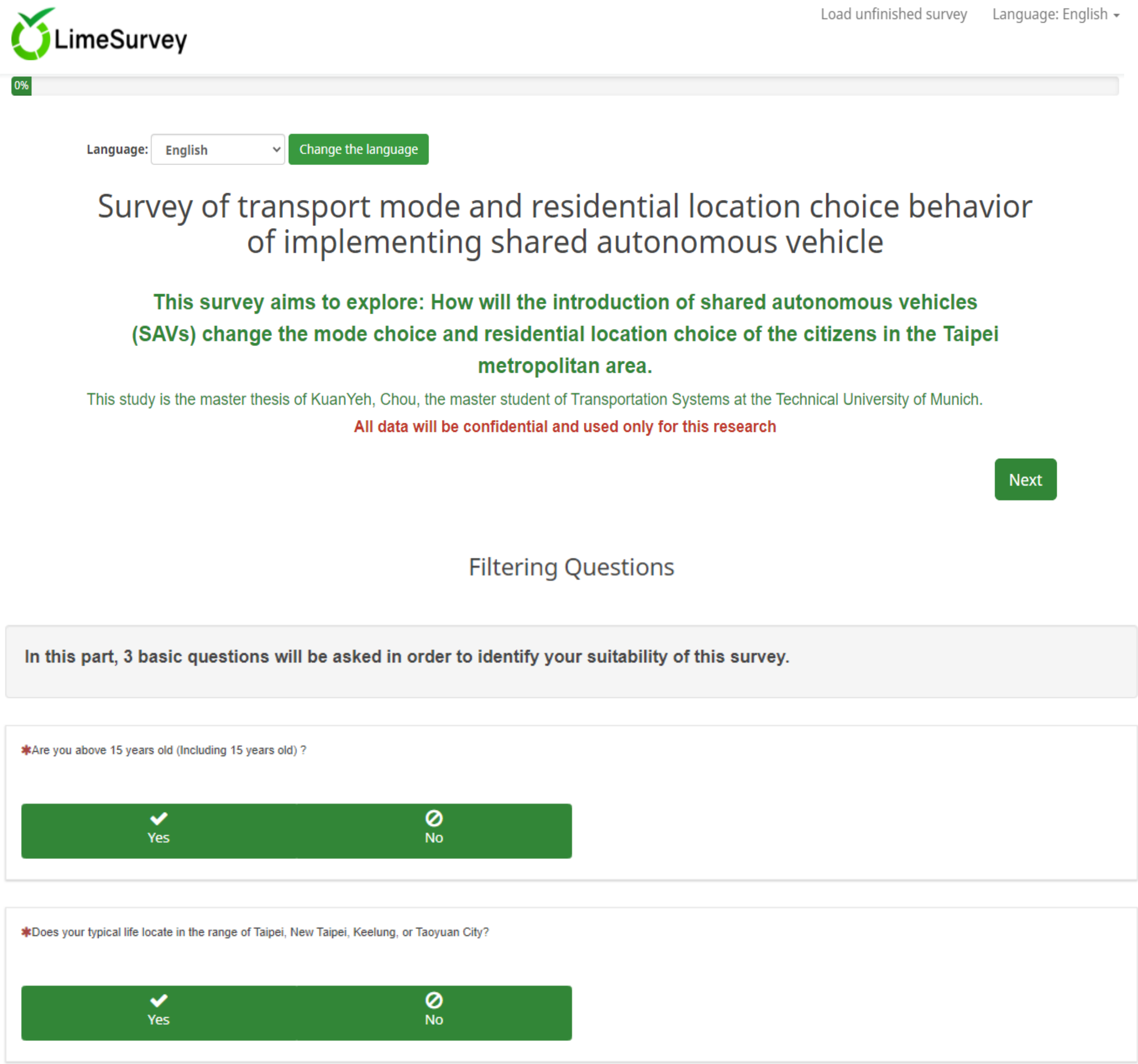
Appendix: Design of SP survey



LimeSurvey

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Survey of transport mode and residential location choice behavior of implementing shared autonomous vehicle

This survey aims to explore: How will the introduction of shared autonomous vehicles (SAVs) change the mode choice and residential location choice of the citizens in the Taipei metropolitan area.

This study is the master thesis of KuanYeh, Chou, the master student of Transportation Systems at the Technical University of Munich.

All data will be confidential and used only for this research

Next

Filtering Questions

In this part, 3 basic questions will be asked in order to identify your suitability of this survey.

*Are you above 15 years old (Including 15 years old) ?

Yes No

*Does your typical life locate in the range of Taipei, New Taipei, Keelung, or Taoyuan City?

Yes No

Part 1. Characteristic of travel behavior

In this part, your current travel behavior regarding transport mode of your most frequent trip purpose will be asked.
(Before the COVID-19 Pandemic)

*In a typical week, what is the most frequent purpose for your trips (i.e. the most common reason you leave home)?

Choose one of the following answers

Work	School	Shopping	Errand	Leisure	Family/Friends Visiting
Hospital	Religion	Other			

The entire survey will specifically ask you regarding characteristics of this **trip purpose**

*In a typical week, how many Work trips do you take? (Outbound and return counts as a single trip)

Your answer must be at least 1
Only an integer value may be entered in this field.

time / week

*Which mode do you typically use for your Work trips? (If there is more than one, choose the mode where you spend the **longest time** traveling.)

Choose one of the following answers

Private car	Scooter	Train	High-speed rail	Metro	Bus
Taxi	Cycling	Walking	Car-sharing	Ride-sharing	Scooter-sharing

(The entire survey will specifically ask you regarding characteristics of this **transport mode**)

Bus includes long-distance, company shuttle bus, demand response transit (DRT)

Car-sharing such as Zipcar, iRent, Smart2go

Ride-sharing such as Uber

Scooter-sharing such as GoShare, iRent, WeMO

Example: For respondents who works and choose private car:

*Are you the driver of Private car?

Yes | No

Yes as driver; No as passenger

*How long does it take from your home to reach the usual parking place or boarding stop/station of Private car?

(If you need to transfer beforehand, please include all transfer time that you need for accessing to your main mode from home.)

Your answer must be between 0 and 59
Only an integer value may be entered in this field.

minute(s)

*For your way to the place of Work, what is your "in-vehicle" travel time using mode of Private car?

Your answer must be between 0 and 199
Only an integer value may be entered in this field.

minute(s)

(If you select Walking, enter the total walk time; If you select another mode, only include the time spend on or in the vehicle. **Do not** include waiting time and time spent to or from the vehicle)

*How long does it take for you to the place of Work from the arrival parking place or alighting stop/station of Private car?

(If you need to transfer afterward, please include all transfer time that you need for egressing from your main mode to the destination.)

Your answer must be between 0 and 59
Only an integer value may be entered in this field.

minute(s)

*How much is the parking cost for your single Work trip ?

Your answer must be between 0 and 9000
Only an integer value may be entered in this field.

NTD/Single trip

Example: For respondents who choose metro will additionally shows:

*Do you transfer in your single Work trip ? (Transfer can be between same mode (i.e. Bus to Bus) or different modes (i.e. Bus to Metro))

Yes | No

The transfer will be counted when transferring between all modes **(except transfer from/to walking and cycling)**

*How long is your waiting time at Metro station or waiting spot?

Only numbers may be entered in this field.
Your answer must be between 0 and 200

minute(s)

If you transfer among the same transport mode (e.g. Bus to Bus), please include it in your answer.

*What is the fare for your single Metro trip from your home to Work?

Your answer must be between 0 and 9000
Only an integer value may be entered in this field.

NTD/Single trip

Note: For the chosen mode, the related questions according to Table 10 will be shown to respondent

Part 2. User perception toward sharing and autonomous mobility

In this part, your perception toward sharing and autonomous mobility will be asked.

*Are you aware of and have you used car/scooter-sharing services?

Choose one of the following answers

Neither aware nor used | Aware but not used | Aware and used

*Are you aware of and have you used ride-sharing such as Uber?

Choose one of the following answers

Neither aware nor used | Aware but not used | Aware and used

*Are you aware of autonomous vehicles (AVs)?

(AV is the driverless vehicle that can self-drive to the designated point without human intervention. AV can also detect surrounding objects to avoid crashes, optimize the travel route, and automatically find a parking place. However, regulations of data privacy and accident responsibility are still ambiguous.)

Yes | No

*Are you interested in using Autonomous vehicle ?

Yes | No

*Are you aware of shared autonomous vehicles (SAVs)?

(SAV is one type of AV, which is the shared vehicle that users do not need car-ownership. SAV is an on-demand service that provides door-to-door services with booking in advance. SAV can be used either by yourself or share the ride with others to lower the cost but spend more time picking up and dropping off other passengers.)

Yes | No

*Are you interested in using shared autonomous vehicle (SAV) ?

Yes | No

Note: If respondents choose not aware of either AV or SAV then the interest questions will not be shown

Part 3. Characteristic of Residential location

In this part, the characteristics of your residential location property, and the environment of your property will be asked.

*Where is the current city and district of your residential location ?

Choose one of the following answers

Please choose...

*Where is the location of your trip destination according to your previous choice ?

Choose one of the following answers

Please choose...

*What is your property type ?

Choose one of the following answers

Owned property | Rent property

*What is your cost of the property ? (NTD)

Choose one of the following answers

Under 5 million	5-10 million	10-15 million	15-20 million	20-25 million	25-30 million
30-35 million	35-40 million	40-45 million	45-50 million	50-100 million	Above 100 million

*To what extent the following reasons affect your choice of residential location ?

1 (very unrelated) to 5 (very related)

	1	2	3	4	5
Cost of the property	○	○	○	○	○
Accessibility to amenities (e.g. Grocery, Park, etc)	○	○	○	○	○
Transportation factor (e.g. Close to your place, near public transit stations, or travel cost)	○	○	○	○	○
Living quality (e.g. The level of physical and psychological satisfaction with living environment)	○	○	○	○	○
Proximity to family or relatives	○	○	○	○	○

If you have the other reason, then please fill this reason in the next question.

Part 4. Stated Mode Choice Experiment for introduction of Shared autonomous vehicles (SAVs)

In this part, there will be a short introduction to shared autonomous vehicles (SAVs). Then you will be asked for choosing 1 preferred transport alternatives among the following 3 alternatives.

Alternatives:

Current alternative

Alternative 1: SAVs without ride-sharing

Alternative 2: SAVs with ride-sharing

The followings are characteristics of SAVs:

1. Without car-ownership

Users do not need to own a car, they book SAVs for each time when necessary.

2. Provide ride-sharing services

SAVs can be used with sharing the ride with others. More travel time is needed to pick up other passenger but costs can be shared.

(Ride-sharing: Travel with not own vehicle and travel with other passengers that on his/her way)

3. Combined with Public transportation

Except for door to door services, the SAVs can be one part of the public transport trip.

Example: Private car user with out-of- and in-vehicle time 3 and 60 minutes, parking cost 100 NTD:

*Scenario 1:

- SAV fare: 40 NTD base cost + **4 NTD/km** follow-up distance
- Waiting time: **5 minutes** for SAV without ride-sharing, **6 minutes** for SAV with ride-sharing

Please choose **1** of your most preferred alternative among the following 3 alternatives.

Travel cost and travel time of the single Work trip

	Current Alternative	Alternative 1 SAV without ride-sharing	Alternative 2 SAV with ride-sharing (Share with 1 other passenger)
Total Travel Cost	190 NTD	156 NTD	90 NTD
Total Travel time	63 min	65 min	78 min
Waiting time	0 min	5 min	6 min

Note: Total travel cost and travel time are estimated based on your previous answers.

Choose one of the following answers

Current Alternative | Alternative 1 | Alternative 2

Scenario 2:

- SAV fare: 40 NTD base cost + **8 NTD/km** follow-up distance
- Waiting time: **5 minutes** for SAV without ride-sharing, **6 minutes** for SAV with ride-sharing

Please choose **1** of your most preferred alternative among the following 3 alternatives.

Travel cost and travel time of the single Work trip

	Current Alternative	Alternative 1 SAV without ride-sharing	Alternative 2 SAV with ride-sharing (Share with 1 other passenger)
Total Travel Cost	190 NTD	272 NTD	160 NTD
Total Travel time	63 min	65 min	78 min
Waiting time	0 min	5 min	6 min

Note: Total travel cost and travel time are estimated based on your previous answers.

Choose one of the following answers

Current Alternative | Alternative 1 | Alternative 2

Scenario 3:

- SAV fare: 40 NTD base cost + **4 NTD/km** follow-up distance
- Waiting time: **10 minutes** for SAV without ride-sharing, **12 minutes** for SAV with ride-sharing

Please choose **1** of your most preferred alternative among the following 3 alternatives.

Travel cost and travel time of the single Work trip

	Current Alternative	Alternative 1 SAV without ride-sharing	Alternative 2 SAV with ride-sharing (Share with 1 other passenger)
Total Travel Cost	190 NTD	156 NTD	90 NTD
Total Travel time	63 min	70 min	84 min
Waiting time	0 min	10 min	12 min

Note: Total travel cost and travel time are estimated based on your previous answers.

Choose one of the following answers

Current Alternative | Alternative 1 | Alternative 2

Scenario 4:

- SAV fare: 40 NTD base cost + **8 NTD/km** follow-up distance
- Waiting time: **10 minutes** for SAV without ride-sharing, **12 minutes** for SAV with ride-sharing

Please choose **1** of your most preferred alternative among the following 3 alternatives.

Travel cost and travel time of the single Work trip

	Current Alternative	Alternative 1 SAV without ride-sharing	Alternative 2 SAV with ride-sharing
Total Travel Cost	190 NTD	272 NTD	160 NTD
Total Travel time	63 min	70 min	84 min
Waiting time	0 min	10 min	12 min

Note: Total travel cost and travel time are estimated based on your previous answers.

Choose one of the following answers

Current Alternative | Alternative 1 | Alternative 2

Appendix A: Design of SP survey

Example: Metro user with out-of- and in-vehicle time 23 and 40 minutes, fare cost 30 NTD

***Scenario 1:**

- SAV fare: 40 NTD base cost + **4 NTD/km** follow-up distance
- Waiting time: **5 minutes** for SAV without ride-sharing, **6 minutes** for SAV with ride-sharing

Please choose **1** of your most preferred alternative among the following 3 alternatives.

Travel cost and travel time of the single Work trip

	Current Alternative	Alternative 1 SAV without ride-sharing	Alternative 2 SAV with ride-sharing (Share with 1 other passenger)
Total Travel Cost	30 NTD	127 NTD	72 NTD
Total Travel time	63 min	50 min	60 min
Waiting time	3 min	5 min	6 min

Note: Total travel cost and travel time are estimated based on your previous answers.

Choose one of the following answers

Current Alternative | Alternative 1 | Alternative 2

***Scenario 2:**

- SAV fare: 40 NTD base cost + **8 NTD/km** follow-up distance
- Waiting time: **5 minutes** for SAV without ride-sharing, **6 minutes** for SAV with ride-sharing

Please choose **1** of your most preferred alternative among the following 3 alternatives.

Travel cost and travel time of the single Work trip

	Current Alternative	Alternative 1 SAV without ride-sharing	Alternative 2 SAV with ride-sharing (Share with 1 other passenger)
Total Travel Cost	30 NTD	213 NTD	125 NTD
Total Travel time	63 min	50 min	60 min
Waiting time	3 min	5 min	6 min

Note: Total travel cost and travel time are estimated based on your previous answers.

Choose one of the following answers

Current Alternative | Alternative 1 | Alternative 2

*Scenario 3:

- SAV fare: 40 NTD base cost + **4 NTD/km** follow-up distance
- Waiting time: **10 minutes** for SAV without ride-sharing, **12 minutes** for SAV with ride-sharing

Please choose **1** of your most preferred alternative among the following 3 alternatives.

Travel cost and travel time of the single Work trip

	Current Alternative	Alternative 1 SAV without ride-sharing	Alternative 2 SAV with ride-sharing (Share with 1 other passenger)
Total Travel Cost	30 NTD	127 NTD	72 NTD
Total Travel time	63 min	55 min	66 min
Waiting time	3 min	10 min	12 min

Note: Total travel cost and travel time are estimated based on your previous answers.

Choose one of the following answers

Current Alternative | Alternative 1 | Alternative 2

*Scenario 4:

- SAV fare: 40 NTD base cost + 8 **NTD/km** follow-up distance
- Waiting time: **10 minutes** for SAV without ride-sharing, **12 minutes** for SAV with ride-sharing

Please choose **1** of your most preferred alternative among the following 3 alternatives.

Travel cost and travel time of the single Work trip

	Current Alternative	Alternative 1 SAV without ride-sharing	Alternative 2 SAV with ride-sharing (Share with 1 other passenger)
Total Travel Cost	30 NTD	213 NTD	125 NTD
Total Travel time	63 min	55 min	66 min
Waiting time	3 min	10 min	12 min

Note: Total travel cost and travel time are estimated based on your previous answers.

Choose one of the following answers

Current Alternative | Alternative 1 | Alternative 2

Note: The calculation of attributes of each mode and SAV alternatives are based on Table 10 and Table 11

Part 5. Stated Residential Location Choice Experiment for introduction of SAVs

In this part, you will be asked for choosing 1 preferred residential location alternative among the following 4 alternatives.

Alternatives:

Current alternative

Alternative 1: Only change to SAVs without moving

Alternative 2: Change to SAVs and move farther from place of Work

Alternative 3: Change to SAVs and move closer to place of Work

Example: Private car user with out-of- and in-vehicle time 3 and 60 minutes, parking cost 100 NTD

*Scenario 1:

- Only consider a possible shift to SAV without ride-sharing
- SAV fare: 40 NTD base cost + 4 NTD/km follow-up distance
- Waiting time: **5 minutes**

Please choose **1** of your most preferred alternative among the following 4 alternatives:

	Current Alternative	Alternative 1 Only change to SAV without moving	Alternative 2 Change to SAV and move farther from 台北市 松山區	Alternative 3 Change to SAV and move closer to 台北市 松山區
Housing cost	15-20 million NTD	15-20 million NTD	Halve the Price	Double the Price
Travel Cost (Monthly)	5600 NTD	6240 NTD	9840 NTD	2640 NTD
Travel time (Single trip)	63 mins	65 mins	110 mins	20 mins

Note: The monthly travel cost is estimated based on the travel time, trip frequency, and travel cost you previously answered

Choose one of the following answers

Current Alternative | Alternative 1 | Alternative 2 | Alternative 3

*Scenario 2:

- Only consider a possible shift to SAV without ride-sharing
- SAV fare: 40 NTD base cost + 8 NTD/km follow-up distance
- Waiting time: **10 minutes**

Please choose **1** of your most preferred alternative among the following 4 alternatives:

	Current Alternative	Alternative 1 Only change to SAV without moving	Alternative 2 Change to SAV and move farther from 台北市 松山區	Alternative 3 Change to SAV and move closer to 台北市 松山區
Housing cost	15-20 million NTD	15-20 million NTD	Halve the Price	Double the Price
Travel Cost (Monthly)	5600 NTD	10880 NTD	18080 NTD	3680 NTD
Travel time (Single Trip)	63 mins	70 mins	115 mins	25 mins

Note: The monthly travel cost is estimated based on the travel time, trip frequency, and travel cost you previously answered

Choose one of the following answers

Current Alternative | Alternative 1 | Alternative 2 | Alternative 3

✱Scenario 1:

- Only consider a possible shift to **SAV with ride-sharing (Share with 1 other passenger)**
- SAV fare: 40 NTD base cost + **4 NTD/km** follow-up distance
- Waiting time: **6 minutes**

Please choose **1** of your most preferred alternative among the following 4 alternatives:

	Current Alternative	Alternative 1 ONly change to SAV without moving	Alternative 2 Change to SAV and move farther from 台北市 松山區	Alternative 3 Change to SAV and move closer to 台北市 松山區
Housing cost	15-20 million NTD	15-20 million NTD	Halve the Price	Double the Price
Travel Cost (Monthly)	5600 NTD	3600 NTD	5760 NTD	1440 NTD
Travel time (Single Trip)	63 mins	78 mins	132 mins	24 mins

Note: The monthly travel cost is estimated based on the travel time, trip frequency, and travel cost you previously answered

Choose one of the following answers

Current Alternative | Alternative 1 | Alternative 2 | Alternative 3

✱Scenario 2:

- Only consider a possible shift to **SAV with ride-sharing (Share with 1 other passenger)**
- SAV fare: 40 NTD base cost + **8 NTD/km** follow-up distance
- Waiting time: **12 minutes**

Please choose **1** of your most preferred alternative among the following 4 alternatives:

	Current Alternative	Alternative 1 ONly change to SAV without moving	Alternative 2 Change to SAV and move farther from 台北市 松山區	Alternative 3 Change to SAV and move closer to 台北市 松山區
Housing cost	15-20 million NTD	15-20 million NTD	Halve the Price	Double the Price
Travel Cost (Monthly)	5600 NTD	6400 NTD	10720 NTD	2080 NTD
Travel time (Single Trip)	63 mins	84 mins	138 mins	30 mins

Note: The monthly travel cost is estimated based on the travel time, trip frequency, and travel cost you previously answered

Choose one of the following answers

Current Alternative | Alternative 1 | Alternative 2 | Alternative 3

Note: The calculation of attributes of each alternative are based on Table 15, 16, and 17

Part 6. Socio-demographic characteristics

In this part, your socio-demographic characteristics will be asked.

(This is the last question set)

*What is your gender?

Female | Male

*What is your age?

Choose one of the following answers

15 - Under 18 | 18 - Under 20 | 20 - Under 30 | 30 - Under 40 | 40 - Under 50 | 50 - Under 60 | 60 - Under 65 | 65 and above

*What is your marital status?

Choose one of the following answers
If you choose 'Other:' please also specify your choice in the accompanying text field.

Single | Married | Other

*What is your occupation?

Choose one of the following answers
If you choose 'Other:' please also specify your choice in the accompanying text field.

Public Employees | Technology Industry | Financial Industry | Business Services | Service Industry | Agricultural Industry | Freelance | HouseKeeper | Student | Retired | Other

*What is your highest education level?

Choose one of the following answers

Under Junior high sch | Senior high school | University | Master | PhD

*What is the household size of your current living place? (Include all of the members and yourself)

Choose one of the following answers

1 | 2 | 3 | 4 | 5+

*How many children in your household? (Under 15 years old)

Choose one of the following answers

0 | 1 | 2 | 3 | 4+

*How many people are currently full-time workers in your household? (Include yourself)

Choose one of the following answers

| 0 | 1 | 2 | 3 | 4+ |

*What is the range of your monthly household income? (NTD)
(Include your personal income)

Choose one of the following answers

| Under 10,000 | 10,000 - 20,000 | 20,000 - 40,000 | 40,000 - 60,000 | 60,000 - 80,000 | 80,000 - 100,000 |
| 100,000 - 150,000 | 150,000 - 200,000 | 200,000- 300,000 | Above 300,000 |

*How many cars in your household? (Include your own car)

Choose one of the following answers

| 0 | 1 | 2 | 3 | 4+ |

*How many scooters in your household? (Include your own scooter)

Choose one of the following answers

| 0 | 1 | 2 | 3 | 4+ |

*How many people in your household have car licenses? (Include yourself)

Choose one of the following answers

| 0 | 1 | 2 | 3 | 4+ |

*How many people in your household have scooter license? (Include yourself)

Choose one of the following answers

| 0 | 1 | 2 | 3 | 4+ |

*Do you have a car license?

| Yes | No |

*Do you have a scooter license?

| Yes | No |

Feedback

Feel free to comment feedback in the following column.

Please leave your email if you want to participate in the prize draw. **(Winner will be informed by email on 21.09.2020)**