Article

Research on the Mode Choice Intention of the Elderly for Autonomous Vehicles Based on the Extended Ecological Model

Huiqian Sun, Peng Jing *, Mengxuan Zhao, Yuexia Chen, Fengping Zhan and Yuji Shi

School of Automotive and Traffic Engineering, Jiangsu University, Zhenjiang 212013, China;
sun_huiqian@yeah.net (H.S.); zhaomengxuango@163.com (M.Z.); cyx08@126.com (Y.C.); fpzhan@126.com (F.Z.);
yujishi@ujs.edu.cn (Y.S.)
* Correspondence: jingpeng@ujs.edu.cn

Received: 16 November 2020; Accepted: 17 December 2020; Published: 20 December 2020

Abstract: Due to the elderly’s limited physical ability, their mode choice behavior with particular demand for the traffic system is significantly distinguished compared to young people. The emergence of Autonomous Vehicles (AVs) and Shared Autonomous Vehicles (SAVs) will allow the elderly to travel independently and offer more mode choices. However, emerging vehicles will continue to coexist with other traditional modes such as public transport. This paper aims to explore the internal mechanism of the elderly’s choice behavior among public transport, AVs, and SAVs. We integrated the relevant factors by expanding the ecological model and used the Multiple Indicators and Multiple Causes (MIMIC) model to analyze the constructs’ relationship. The results show that the elderly believe that public transport, AVs, and SAVs are useful and convenient travel modes for themselves, affecting intention significantly. In addition, the elderly’s well-being and social influence during travel are also significant constructs for their behavioral intention. The research could provide academic supports for the traffic management departments when making relevant policies and measures for the elderly.

Keywords: elderly; travel mode; choice behavior; extended ecological model; autonomous vehicles

1. Introduction

China is prospecting a larger proportion of elderly people in the total population, and this trend is expected to increase in coming years, which has brought a challenge to society. The travel problem related to the quality of life for the elderly has especially attracted researchers [1]. Traffic travel behavior is the fundamental guarantee for the elderly to maintain their daily activities. The physical condition of the elderly and the current traffic modes have become obstacles to their travel activities. The regulations concerning drivers stipulated that older people over 70 years cannot apply for a license before 2020. Some elderly people report problems such as “squeeze, unstable, and not to come” on the bus, which weakens their mobility. Mobility is closely related to the physical condition and quality of life of the elderly [2,3] and promotes society’s overall development [4].

Hu et al. found that an average of 80% of the elderly in China prefer to use walk and public transport, which would increase more than 90% with age, while only less than 3% choose driving [5]. On the contrary, older travelers are almost 90% car-oriented, with low public transport usage levels, less than 2% in North America [6]. That indicates there are enormous different travel patterns for the elderly between China and North America. Therefore, we excluded the mode of driving in this study. However, with Chinese economic development and increased individual income, more people are accustomed to driving. In 2020, the Chinese elderly, more than 70 years old, could still apply for their...
license if they have a good physical condition. We could anticipate that the percent of the elderly choosing to drive a car will increase shortly in China. Therefore, the exclusion of driving from the elderly’s travel mode choice set is the limitation of this study. We will introduce the driving option in our future research as a benchmark.

The effect of Autonomous Vehicles (AVs, we listed all the Glossary) on the transport system, such as travel behavior, traffic safety, and congestion, has been much discussed in the past half-decade [7]. Harper et al. proposed that the emergence of AVs and Shared Autonomous Vehicles (SAVs) will provide more choices for the elderly, enhance their travel convenience and mobility [8]. AVs will replace traditional cars and become an emerging travel choice, bringing the ultimate experience of comfort, safety, and convenience to travelers in the future. AVs are faster and can improve road capacity and alleviate urban traffic congestion; they are more environmentally-friendly and can improve fuel efficiency and reduce exhaust pollution [9]. At the same time, Nuzzolo et al. found AVs could provide an opportunity to reduce air pollution in the cities’ central areas [10]. Tan et al. also demonstrated the driverless cars’ potential implications on sustainable tourism [11]. Liu et al. reported that the public would intend to accept AVs’ risk when AVs are more environmentally-friendly [12]. The integration of AVs and “shared travel” will be realized with the development of autonomous driving technology and the sharing economy. Experts predict that SAVs will also become an emerging travel mode, which will replace traditional taxis and net cars in the future [13].

However, whether AVs or SAVs may take a long time from the current development stage to mature promotion and full popularity stage. Technology developments should be accompanied by researching individuals’ habits and consumption motivations in the population [14]. When the technology becomes mature, the implementation of legislation and social mentality adjustment should be solved to enable travelers to enjoy safe, comfortable, and free travel on their own [15]. For the elderly, the emergence of AVs and SAVs is indeed a boon to meeting the need for independent travel, but the ability to accept and adapt to new things is still unknown, the long-term use of buses will not change immediately. Levin and Stephen proposed that AVs and SAVs will coexist with public transport for a long time in the future transportation system [16]. To our best knowledge, there are few literatures concerning AVs’ impact on the elderly’s mode choice behavior, which is essential for the elderly’s later life quality in the future. Therefore, it is meaningful to investigate the elderly’s mode choice between public transport, AVs, and SAVs.

In recent years, the ecological model has been gradually applied to the elderly’s travel behavior. Hough, Cao, and Handy proved the ecological model’s applicability in the elderly’s travel behavior [17]. Mifsud, Attard, and Ison found that three types of independent variables in the ecological model: personal factors, social factors, and environmental factors affect older people’s travel behaviors [18]. Several articles indicated that the ecological model has the explanation strength in the elderly’s travel behaviors. However, researchers have focused on the impact of observable variables without further considering their psychological state. In particular, observable variables may not be sufficient to predict future older populations’ travel mode choice behavior, given their escalating physical and mental level demands in modern society. Therefore, one of the major gaps in the elderly’s travel behaviors is the lack of psychological variables in applying the ecological model. In this study, an extended ecological model involving psychological variables and travel attributes was proposed to comprehensively analyze the elderly’s mode choice behavior.

Furthermore, elders’ travel modes vary due to the differences between individual countries regarding social systems and cultural backgrounds. To our knowledge, significant development and experiments of the ecological model about the elderly’s travel behaviors have been obtained in developed countries, including travel behavior of older women in the USA [13], public transport use among older adults in Australia [19], and the elderly’s mode choice between cars and buses in Malta [18]. However, the study of the elderly’s travel behavior through ecological models rarely conducted, leading to another gap in this field.
The majority of current research into the elderly’s travel behavior was realized by examining travel mode choices related to buses, walking, cycling, and cars. As a forthcoming advanced transport, autonomous driving technology would provide great convenience to the elderly or disabled [8]. The authors also proposed that AVs and SAVs could be used as an alternative to traditional cars, and eventually become one of the most dominating mode choices among older adults. Surprisingly, AVs and SAVs were very few in the elderly travel mode choices domain.

Overall, this study attended to supplement research on elderly travel behavior. It may be the first to take the Chinese elderly as the research object and put forward an extended ecological model to explore their mode choices among public transport, AVs, and SAVs.

The objective of this study includes: (1) exploring the adaptability and application of the extended ecological model in the elderly’s mode choice behavior in the future; (2) making a deeper understanding of the elderly’s attitude towards the AVs and SAVs, and discovering the mechanism concerning the relationship among constructs affecting travel mode choice behavior; (3) proposing suggestions for manufacturers to develop AVs and SAVs to serve for the elderly’s travel need and providing support for the government to introduce policies and measures to promote the application of AVs and SAVs in the market. We found that the elderly believe that public transport, AVs, and SAVs are useful and convenient travel modes for themselves, affecting intention significantly. In addition, the elderly’s well-being and social influence during travel are also significant constructs for their mode choice intention.

The remainder of this paper proceeds as follows. Section 2 reviews the background; Section 3 illustrates the extended ecological model; Section 4 presents the data survey and models, and Section 5 describes the results and discussions. Finally, Section 6 reveals the limitation and conclusion.

### 2. Background

This study aims to analyze the mode choice behaviors of the elderly towards public transport, AVs, and SAVs, which are based on the elderly’s travel needs and the extended ecological model. Before the analysis, this paper reviewed the research of predecessors.

#### 2.1. Travel Mode Choice of the Elderly According to Autonomous Vehicle

With the development of transportation, travel modes are becoming more and more diversified in recent years. Although the elderly appear to be more mobile than earlier generations, their mobility levels lag behind young people [20]. Smeltzer mentioned that the elderly’s travel demand goes unsatisfied under an aging population’s gradually grave background [21]. Several studies focused on the elderly’s travel demand and tried to improve their travel conditions [17,18,22,23]. We listed the related research in Table 1. The mode choice set of these studies include bus, private car, walking, etc.

| Authors (Year)      | Theoretical Model | Travel Mode | Explanatory Variables                                      |
|---------------------|-------------------|-------------|------------------------------------------------------------|
| Hough, Cao, and Handy 2008 [17] | The ecological model | Private car | Individual factors, Social environment, Physical environment |
| Schmoecker et al. 2008 [23]          | -                 | Bus, Private car | Personal travel characteristic, Family travel characteristic, Travel attribute |
| Amen 2014 [24]         | -                 | Bus, Private car | Personal characteristic, Family characteristic, Weather conditions, Built environment |
| Rahman et al. 2016 [25]    | -                 | Private car | Socioeconomic variables                                    |
| Liu et al. 2016 [26]     | -                 | Bus, Walking | Personal characteristic, Family characteristic             |
| Mifsud, Attard, and Ison 2017 [18] | The ecological model | Bus, Private car | Individual factors, Social environment, Physical environment |
| Payyanadan and Lee 2018 [22]   | -                 | Sharing car | Socioeconomic variables, Travel characteristic             |

Note: The sign “-” means no theoretical model is used in the literature.
AVs technology has made rapid advances in recent years, which are likely to change the future of mobility [27]. Harper et al. suggested that AVs technology may provide an excellent convenience for the elderly who cannot drive due to poor physical function [8]. Hence, AVs may become one of the elderly’s travel modes in the future. However, most of the studies considering the AVs travel mode choice mainly focus on commuters (see Table 2). There is little literature that focuses on the elderly mode choice among AVs or SAVs. It may be the initial attempt to predicate the impact of AVs and SAVs’ emergence on the elderly travel behavior intention.

Table 2. The research for travel mode choice behavior of autonomous vehicles.

| Authors (Year)            | Subject           | Travel Mode                        | Explanatory Variables                  |
|---------------------------|-------------------|------------------------------------|----------------------------------------|
| Levin and Boyles 2015 [16]| commuter          | Public transport, AVs, SAVs        | Travel attribute                       |
| Lamondia et al. 2016 [27] | traveler          | Bus, Private car, AVs, Bus         | Socioeconomic variables, Travel attribute |
| Yap, Correia, and van Arem 2016 [28] | commuter | Public transport, Cycle, Private car, AVs | Socioeconomic variables, Latent attitude variables |
| J. Liu et al. 2017 [29]   | urban resident    | Private car, SAVs                  | Socioeconomic variables, Travel attribute |
| Haboucha, Ishaq, and Shiftan 2017 [30] | commuter | Bus, AVs, SAVs | Socioeconomic variables, Travel attribute, Psychological variables |
| Moreno et al. 2018 [13]   | traveler          | AVs, SAVs                          | Socioeconomic variables, Travel attribute, Psychological variables |
| Nazari, Noruzoliaee, and Mohammadian 2018 [31] | traveler | Autonomous taxi, AVs, SAVs | Socioeconomic variables, Travel attribute, Psychological variables, Environmental variables |
| Pakusch et al. 2018 [32]  | traveler          | Traditional car, Traditional car-sharing, AVs, SAVs, Bus | Socioeconomic variables, Travel attribute, Psychological variables |
| Menon et al. 2019 [15]    | Private car owner | Traditional car, SAVs              | Socioeconomic variables, Psychological variables |
| Pettigrew, Dana, and Norman 2019 [33] | traveler | AVs, SAVs                          | Socioeconomic variables, Travel attribute, Psychological variables |
| Acheampong and Cugurullo 2019 [34] | traveler | Bus, AVs, SAVs | Socioeconomic variables, Psychological variables |

2.2. Application of the Ecological Model in Elderly Travel Mode Choice

Since Hough introduced the ecological model into older adults’ travel behavior [17]. Truong and Somenahalli explored the elderly’s use of public transport through the ecological model and verified its strong explanatory power [19]. Mifsud, Attard, and Ison used the ecological model to analyze older people’s travel mode choice in Malta, indicating that the ecological model affects the elderly’s travel behaviors through three independent variables: personal factors, social factors, and environmental factors [18]. Considering specific cultural and social contexts may differ in Chinese elderly travel patterns with abroad counterparts [20], there is an urgent need to construct a theoretical framework to understand elderly travel behavior in China, improving their life quality [35]. Therefore, we first attempt to introduce the ecological model into the Chinese elderly’s travel mode choice.

The ecological model takes less account of psychological factors and travel attributes [17]. Xia believed it is necessary to focus on older adults’ travel attributes and psychology to understand
their mode choice behavior [36]. On the one hand, exploring travel attribute variables could provide a clearer understanding of the elderly’s mode choice preferences [1]. On the other hand, psychological factors have an essential role in predicting and understanding the elderly’s travel behavior [1,37]. Therefore, this research might first extend the ecological model by the variables related to travel attributes and psychology.

3. Extended Ecological Model

3.1. Extended Travel Attribute Variable

Travel attributes refer to travel modes’ inherent characteristics, including quantitative (travel cost, travel time) and qualitative factors (comfort, reliability, timeliness). Travel time has always been a crucial variable in measurement. Truong and Somenahalli reported that too long travel time would bring fatigue to the elderly, reduce the initiative of the elderly, and affect their quality of life [19]. However, the length of travel time often contradicts the travel cost. Rahman et al. showed that public transport’s preferential policies would attract some elderly people with lower retirement wages [25]. Therefore, travel cost could determine the elderly’s Behavioral Intention (BI).

When traffic congestion becomes a severe social problem, travel time variability would greatly influence the private car’s choice behavior. Due to the same reason, public transport’s travel time reliability also needs to be improved, although there are bus priority lanes. Krueger, Rashidi, and Rose have pointed out that AVs’ emergence will alleviate traffic congestion because artificial intelligence technology can keep AVs a safe distance from the front car at a steady speed [38]. However, it is unknown whether the travel time’s variability on the way can be eliminated in the future, so we introduced the variable of travel variability time. What is more, Olawole and Aloba proposed that travel comfort plays a vital role in the elderly’s mode choice behavior and travel mobility [4]. Therefore, travel comfort is also used in our study.

To sum up, we select four travel attributes to analyze the elderly’s mode choice behavior: travel time, travel variability time, travel cost, and travel comfort. There will be mutual constraints among the four variables for AVs, SAVs, and public transport, which depend on the actual demand and self-choice preference of the elderly. Therefore, it is of practical significance to study travel attributes’ influence on choice intention in improving the service quality of travel mode itself and meeting the travel demand of the elderly.

3.2. Theoretical Framework

We extend the original ecological model by introducing PU, PE, AT, SWB, and SI. Additionally, the four travel attributes, including travel time, travel variability time, travel cost, and travel comfort, as shown in Figure 1.

Figure 1. The theoretical framework of mode choice behavior for the elderly.
4. Methodology

4.1. Questionnaire Survey and Implementation

We use a survey questionnaire to obtain empirical data. The questionnaire contains three parts. The first one is the ecological model's original constructs: personal factors, social factors, and environmental factors. The second part includes the expanded constructs: PU, PE, AT, SWB, and SI. The third part is the extended travel attributes: travel time, travel variability time, travel cost, and travel comfort. In this study, we use three question items to measure the extended latent variable for the elderly, using the Likert five-scale. We use the orthogonal design method to set three effective selection scenarios for each mode. The respondents need to choose among the three options for each scenario. We presented the question items concerning constructs, as shown in Table 3.

### Table 3. Sources of constructs and items used in the research.

| Constructs                  | Item                                                                 | Source                                   |
|-----------------------------|----------------------------------------------------------------------|------------------------------------------|
| Perceived Usefulness (PU)   | I expect that the following travel modes are useful for my life in the future. | (Davis et al., 1989) [39]               |
|                             | I expect that the following travel modes are helpful for me in the future. |                                         |
|                             | I expect that the following travel modes are functional for me in the future. |                                         |
| Perceived Ease of use (PE)  | I think the following travel modes are easy for me in the future.       | (Davis et al., 1989) [39]               |
|                             | I think the operation of the following travel modes is easy for me in the future. |                                         |
|                             | I think it is easy for me to use the facilities and services of the following travel modes. |                                         |
| Attitude (AT)               | I prefer to using the following travel modes in the future.             | (Davis et al., 1989; Zhang et al., 2019) [39,40] |
|                             | I think it is a good idea to use the following travel modes in the future. |                                         |
|                             | I support the use of the following travel modes in the future.          |                                         |
| Behavioral Intention (BI)   | I will intend to use following travel modes in the future.              | (Panagiotopoulos and Dimitrakopoulos, 2018) [41] |
|                             | I will use the following travel modes in the future.                    |                                         |
|                             | I will recommend my relatives and friends to use the following travel modes in the future. |                                         |
| Subjective Well-Being (SWB) | I believe the following travel modes are close to my ideal in the future. | Bergstad et al. (2011) [42]             |
|                             | I am satisfied with the following travel modes in the future.           |                                         |
|                             | When I choose one of the following travel modes to use in the future,    |                                         |
|                             | I believe I have the best one.                                         |                                         |

We collected data in the urban area of Suzhou, Jiangsu Province, China, from July 4 to July 8, in 2018. Suzhou lies in the south of Jiangsu Province, east of China, with an area of 8657 km², and a population of 10.72 million. A pre-investigation was conducted among 23 older people (more than 60 years old) randomly before a formal survey. We corrected the wording and sorting errors of the items and re-edited the questionnaire according to their comments and feedback. We randomly sampled and distributed questionnaires in the neighborhood, small squares, and other crowded places. The participants were asked to complete the questionnaire if they gave consent to accept. If the participants had problems during the survey, the investigators would use objective words to describe and explain the questionnaire. A total of 600 questionnaires were distributed, and 524 were collected. The recovery rate was 87.33%. The questionnaires with apparent incomplete and wrong data (younger than 60 years old) were excluded. A total of 438 participants constituted our final
sample; the effective rate was 83.59%. We believe that the response rate and efficiency of this survey are relatively satisfactory.

4.2. The Models

4.2.1. Multiple Indicators and Multiple Causes (MIMIC) Model

Multiple indicators and multiple causes (MIMIC) model is a simplified structural equation model, which can be used to analyze the relationship among latent variables, and between observed and latent variables [43]. The MIMIC model can deal with multiple latent variables and endogenous indicators simultaneously, and allow the existence of measurement errors, so its theoretical framework is more flexible than other indirect measurement methods.

4.2.2. A Generalized RRM Model (G-RRM)

We applied Biogeme to estimate the generalized random regret minimization model (G-RRM) and analyze travel attributes’ sensitivity to the elderly’s mode choice behavior. We also compared the goodness of fit with the RUM model.

The random regret minimization model (RRM) is based on the regret theory to minimize the regret of travelers’ mode choice [44]. Loomes and Sugden found that RRM is a decision-maker to compare the selected scheme with other options and to minimize the expected regret, that is, to evade the psychology [45]. If another alternative has higher utility, the decision-makers will regret, and vice versa. Chorus investigated that the G-RRM model is more suitable for travelers’ decision-making behavior because the model considers that when decision-makers choose a scheme that minimizes their regrets, some unobservable variables affect the regret value [46]. The elderly have bounded rationality when making travel decisions. G-RRM model could capture the regret avoidance psychology of the elderly more realistically and accurately. Therefore, we choose the G-RRM model to analyze travel attributes.

5. Results and Discussions

5.1. Extended Psychological Latent Variable

5.1.1. Perceived Characteristic and Attitudes

Davis proposed that the Technology Acceptance Model (TAM) ‘s core concept is that users’ acceptance of emerging information technology will affect users’ intentions [39]. Figure 1 shows the framework of TAM. Perceived Usefulness (PU) and Perceived Ease of use (PE) in TAM influence users’ intentions for emerging information technologies. Ma et al. found that Perceived Characteristics (PC) could represent PU and PE for emerging travel modes [47]. Once users have specific knowledge of emerging information technology through external variables, they will have a particular perception of their characteristics. PU and PE act on the users’ Attitude (AT), which could affect Behavioral Intention (BI), and actual behavior occurs, as shown in Figure 2.

![Figure 2. Technology Acceptance Model Framework.](image-url)
In summary, the PC measurement shows high predictive power in applying new technologies, so the elderly’s characteristics and ease of use affect their attitude toward travel modes when AVs are emerging in the traffic system.

5.1.2. Subjective Well-Being

Happiness refers to individuals’ subjective emotional feelings in the travel process, namely Subjective Well-Being (SWB). The elderly’s SWB is significant in studying individual behavior and producing positive feedback on social development and health benefits [37]. Little empirical research concerns the elderly’s travel well-being in China, which may cause the policy-makers’ support for the elderly’s quality of life is not enough.

5.1.3. Social Network

Watts proposed the famous “small world model” in nature, claiming the individual is not only a single existence but a member of a social group [48]. The social network (SN) between people can be seen as a small world model, which indicates that interactions between people can affect their social behavior, as shown in Figure 3. Montazemi and Conrath pointed out that a social network can increase or decrease consumer trust in new technologies and affect usage intentions [49]. Kim, Rasouli, and Timmermans used SN to explore the impact of travel behavior for SAVs through Social Influence (SI) [50].

![Figure 3. Schematic diagram of the social network.](image)

In the process of socialization, the elderly will inevitably absorb or reject some of the other’s views. Therefore, from the perspective of SN, we extend the ecological model using SI.

5.1.4. Hypothesis

The Relationship between PU, PE, and AT

An individual’s behavioral intention is the critical driver of actual behavior [39]. In this study, behavioral intention means the elderly’s usage intentions towards travel modes.

In TAM, PE and PU are considered two crucial factors that directly impacted persons’ attitudes to the new technology [39,51]. PU refers to the degree to which individuals believe that using a particular system would enhance their performance, and PE is defined as the degree to which a person believes that using a particular system would be free of effort [39]. Chen and Chao investigated the travelers’ public transport choice behavior through PU and PE, which significantly affects the AT [52]. Especially focusing on the elderly, we assume that the more the elderly feel easy and useful about travel modes, the more they have a positive attitude to use it in our research, therefore, hypothesis 1 is proposed. In addition, Shang-Yu Chen discovered perceived green usefulness plays an intermediary role between perceived green ease of use and AT for public bicycles [53]. While in the field of the
elderly’s travel mode choice, especially for public transport, AVs and SAVs, few studies concentrate on the relationships between PU and PE, which seems necessary. Hence, we proposed that PE has a direct effect on PU and have hypothesis 2. Moreover, the elderly’s attitude toward travel modes reflects their general evaluation and inclination toward this behavioral intention [54,55]. Thus, hypothesis 3 is formulated. Above all, to investigate the association of PU, PE and AT, the following hypotheses are drawn:

**Hypothesis 1 (H1).** PU and PE have direct positive effects on AT for the elderly’s choice behavior.

**Hypothesis 2 (H2).** PE has a direct positive effect on PU for the elderly’s choice behavior.

**Hypothesis 3 (H3).** AT has a direct positive effect on BI for the elderly’s choice behavior.

The Role of SWB in the Extended Ecological Model

Subjective well-being, one of the most vital factors in this study, is defined as the elderly’s emotional well-being during the travel mode choice process. The more the elderly experience happiness via their engagement in travel by AVs and SAVs, the greater their motivation to make relevant decisions [56]. Therefore, we propose hypothesis 4 supporting that SWB has a positive influence on the elderly’s mode choice intention. In addition, while making choices, AT and PE are positively correlated with happiness and satisfaction [31,57]. It indicated that if the elderly have a positive attitude and feel easy, they enjoy traveling more. Hence, hypothesis 5 is proposed. According to previous studies, the following hypotheses may be correct:

**Hypothesis 4 (H4).** SWB has a significant positive correlation with BI for the elderly’s choice behavior.

**Hypothesis 5 (H5).** AT and PE have significant positive correlations with SWB for the elderly’s choice behavior.

Social Influence (SI)

Social influence refers to the interactions between the elderly and other people, affecting the elderly’s choice behavior. Kim et al. found that individuals tend to change to some extent with the group’s general phenomenon [50]. When an individual realizes that other people think they should choose, they will have the motivation to make relevant decisions [58]. Therefore, it could be inferred that SI would positively impact the AT and BI toward the elderly’s modes choice behavior [50]. Thus, we proposed hypothesis 6 and hypothesis 7:

**Hypothesis 6 (H6).** SI has a positive correlation with BI for the elderly’s choice behavior.

**Hypothesis 7 (H7).** SI has a positive correlation with AT for the elderly’s choice behavior.

5.2. Descriptive Statistical Analysis

As shown in Table 4, we use descriptive statistics on the empirical data collected from the survey, including the ecological model’s original variables: personal factors, social factors, and environmental factors.
As seen in the table, the proportion of men and women in our sample is relatively uniform, and the age is mostly from 60 to 69 years old, accounting for 65.53%. Nearly half of the elderly’s education is in primary or lower secondary schools, and 34.93% of older persons graduate from high school. One-third participants of the sample have monthly income from RMB 3000 to 6000. A total of 37.21% of the elderly are not in good physical condition, and nearly half of the elderly’s mobility depends on their families. We can also see that most elderly still like to participate in social activities; 44.52% occasionally take part in social activities, and 38.59% often participate in social activities. According to the sample, 47.72% of the elderly use public transport every week, even every day. At present, buses are still an essential mode for the elderly.
5.3. Measurement Model

To examine the survey items’ scale reliability, we calculated Cornbrash’s $\alpha$, as shown in Table 5. The minimum value of Cronbach’s $\alpha$ is 0.760, and all values are higher than the recommended minimum value of 0.70. We used the Average Variance Extracted (AVE) values and the construct’s standardized factor loading to test the measurement model’s convergent validity. Convergence validity reflects whether the items used to measure the same structure have internal reliability. The AVE of constructs range from 0.514 to 0.781, and the standard factor loading values were between 0.696 and 0.934, meeting the recommended minimum value of 0.5 [59]. Therefore, the measurement model has good performances in reliability and validity terms.

Table 5. Reliability and validity test results of constructs.

| Constructs                  | Items       | Standardized Factor Loading | Cronbach’s $\alpha$ | AVE   |
|-----------------------------|-------------|-----------------------------|---------------------|-------|
| Public transport            | PT_PU1      | 0.835                       |                     |       |
|                             | PT_PU2      | 0.859                       |                     |       |
|                             | PT_PU3      | 0.795                       |                     |       |
| Perceived usefulness (PU)   | PT_PE1      | 0.827                       |                     |       |
|                             | PT_PE2      | 0.812                       |                     |       |
|                             | PT_PE3      | 0.879                       |                     |       |
| Perceived ease of use (PE)  | PT_AT1      | 0.794                       |                     |       |
|                             | PT_AT2      | 0.841                       |                     |       |
|                             | PT_AT3      | 0.883                       |                     |       |
| Attitude (AT)               | PT_SWB1     | 0.916                       |                     |       |
|                             | PT_SWB2     | 0.908                       |                     |       |
|                             | PT_SWB3     | 0.848                       |                     |       |
| Subjective well-being (SWB)| PT_SI1      | 0.795                       |                     |       |
|                             | PT_SI2      | 0.886                       |                     |       |
|                             | PT_SI3      | 0.813                       |                     |       |
| Social influence (SI)       | PT_BI1      | 0.825                       |                     |       |
|                             | PT_BI2      | 0.872                       |                     |       |
|                             | PT_BI3      | 0.796                       |                     |       |
| Behavioral intention (BI)   | AV_PU1      | 0.742                       |                     |       |
|                             | AV_PU2      | 0.827                       |                     |       |
|                             | AV_PU3      | 0.775                       |                     |       |
| Perceived ease of use (PE)  | AV_PU1      | 0.904                       |                     |       |
|                             | AV_PU2      | 0.836                       |                     |       |
|                             | AV_PU3      | 0.898                       |                     |       |
| Attitude (AT)               | AV_AT1      | 0.755                       |                     |       |
|                             | AV_AT2      | 0.794                       |                     |       |
|                             | AV_AT3      | 0.733                       |                     |       |
| Subjective well-being (SWB)| AV_AT1      | 0.882                       |                     |       |
|                             | AV_AT2      | 0.748                       |                     |       |
|                             | AV_AT3      | 0.778                       |                     |       |
| Social influence (SI)       | AV_PW1      | 0.705                       |                     |       |
|                             | AV_PW2      | 0.856                       |                     |       |
|                             | AV_PW3      | 0.764                       |                     |       |
| Behavioral intention (BI)   | AV_PW1      | 0.748                       |                     |       |
|                             | AV_PW2      | 0.762                       |                     |       |
|                             | AV_PW3      | 0.712                       |                     |       |
Table 5. Cont.

| Constructs                  | Items        | Standardized Factor Loading | Cronbach’s α | AVE   |
|-----------------------------|--------------|----------------------------|--------------|-------|
| SAVs                        |              |                            |              |       |
| Perceived usefulness (PU)   | SAV_PU1      | 0.696                      |              |       |
|                             | SAV_PU2      | 0.746                      | 0.760        | 0.514 |
|                             | SAV_PU3      | 0.725                      |              |       |
| Perceived ease of use (PE)  | SAV_PE1      | 0.802                      |              |       |
|                             | SAV_PE2      | 0.893                      | 0.878        | 0.707 |
|                             | SAV_PE3      | 0.834                      |              |       |
| Attitude (AT)               | SAV_AT1      | 0.727                      |              |       |
|                             | SAV_AT2      | 0.825                      | 0.821        | 0.605 |
|                             | SAV_AT3      | 0.792                      |              |       |
| Subjective well-being (SWB)| SAV_SWB1     | 0.934                      |              |       |
|                             | SAV_SWB2     | 0.844                      | 0.912        | 0.776 |
|                             | SAV_SWB3     | 0.876                      |              |       |
| Social influence (SI)       | SAV_SI1      | 0.888                      |              |       |
|                             | SAV_SI2      | 0.792                      | 0.881        | 0.713 |
|                             | SAV_SI3      | 0.863                      |              |       |
| Behavioral intention (BI)   | SAV_BI1      | 0.863                      |              |       |
|                             | SAV_BI2      | 0.847                      | 0.854        | 0.685 |
|                             | SAV_BI3      | 0.803                      |              |       |

5.4. Multiple Indicators and Multiple Causes (MIMIC) Model

5.4.1. Model Construction and Fitting Effect Analysis

Based on the seven hypothetical relationships proposed above, a path analysis diagram for the decision-making model of the elderly’s mode choice behavior, as shown in Figure 4. The upper and lower rows of rectangular boxes represent the personal factors, social factors, and travel attributes. Ellipses represent latent variables, and rectangles indicate corresponding measurement variables of each latent variable.

![Figure 4. The path analysis of the MIMIC model.](image-url)
The evaluation of the model fitting effect is a prerequisite for the analysis of the results. If the fitting index is not in a reasonable interval, the model needs to be modified. The fitting indicators of the MIMIC model usually include the following: Chi-square degree of freedom ($\chi^2/df$), Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Squared Error of Approximation (RMSEA) and Standardized Root Mean Squared Residual (SRMR). Of course, each indicator has a reasonable interval. Table 6 shows the fit of the structural equation model for the three modes.

Table 6. Evaluation of model fitting indicators.

| Fitting Index | $\chi^2/df$ | CFI  | TLI  | RMSEA | SRMR | Fitting Effect |
|---------------|------------|------|------|-------|------|----------------|
| Reasonable range | <3, Good; <5, Acceptable | >0.90 | >0.90 | <0.05, Excellent; <0.08, Good | <0.08, Acceptable | -- |
| PT            | 3.473      | 0.912 | 0.921 | 0.057 | 0.041 | $\sqrt{\hspace{1cm}}$ |
| AVs           | 3.241      | 0.917 | 0.918 | 0.053 | 0.044 | $\sqrt{\hspace{1cm}}$ |
| SAVs          | 3.059      | 0.915 | 0.920 | 0.049 | 0.043 | $\sqrt{\hspace{1cm}}$ |

5.4.2. The Relationship between Observed and Latent Variables

In this paper, the effects of observed factors on latent variables are discussed according to three modes, such as public transport, AVs, and SAVs. The model analysis results are shown in Tables 7 and 8.

Table 7. Relationship between personal factors with latent variables.

| Variables | Gender | Age | Edu | Income | Career | Physical Health | Mental Health | License |
|-----------|--------|-----|-----|--------|--------|----------------|---------------|---------|
| PT        |        |     |     |        |        |                |               |         |
| PU        | 0.035  | 0.071 * | 0.038 | -0.113 | 0.113  | 0.108 *         | -0.009       | -0.015 * |
| PE        | 0.014  | 0.179 | 1.372 | 0.004  | 0.004  | -0.056 *        | 0.010        | 0.019   |
| AT        | 0.006  | -0.280 | 0.062 | 0.001  | 0.517  | 1.004           | -0.064 *     | 0.431   |
| SWB       | -0.013 | -0.059 | 0.053 | -0.226 | 0.226  | 0.182 **        | -0.103 *     | -0.055 * |
| SI        | 0.042  | 0.061 | -0.007 | 0.043  | 0.093  | 0.087           | 0.066        | 0.049   |

| AVs        |        |     |     |        |        |                |               |         |
| PU        | 0.011  | 0.049 | 0.194 | 0.162 ** | 0.056  | 0.604          | 0.092        | 0.007   |
| PE        | 0.013 * | -0.017 ** | 0.272 ** | 0.099  | 0.113  | 0.075          | -0.611       | 0.084 ** |
| AT        | 0.247  | 0.101 | 0.205 | 0.041  | 0.039 * | 0.049 ***       | -0.055 *     | 1.052   |
| SWB       | 0.406  | 0.308 | 0.177 | 0.118 * | 0.001  | 0.125 **       | 0.412        | 0.010   |
| SI        | 0.088  | -0.052 | 0.005 | 0.010  | 0.022  | 0.037          | -0.043       | 0.002   |

| SAVs        |        |     |     |        |        |                |               |         |
| PU        | 0.042  | 0.507 | 0.065 * | 0.056 * | 0.107  | 0.904          | 0.370        | -0.226 * |
| PE        | 0.033  | -0.026 | 0.047 * | 0.787  | 0.004  | 0.220          | 0.011        | 0.003   |
| AT        | 0.274  | 0.904 | 0.663 | 0.065  | 1.073  | 0.031 **       | 0.558        | 0.060   |
| SWB       | 0.180  | 0.085 * | 0.330 | 0.539  | 0.006  | -0.319 **      | 0.036        | -0.017  |
| SI        | 1.005  | -0.013 | 0.007 | -0.044 | 0.809  | 0.542          | 0.031        | 0.029   |

Note: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

Table 8. Relationship between social factors and travel attributes with latent variables.

| Variables | Living Status | Rely On | Social Activity | Station Distance | Frequency |
|-----------|---------------|---------|----------------|------------------|-----------|
| PT        |               |         |                |                  |           |
| PU        | 0.074         | 0.240   | 0.015          | -0.032 **        | 0.013 *   |
| PE        | 0.009         | -0.189  | 0.004          | -0.107 *         | 1.057     |
| AT        | 0.015         | 0.004   | 0.080          | -0.040           | 0.379 *   |
| SWB       | -0.063        | 0.011   | 0.331          | -0.551           | 0.002     |
| SI        | 0.550         | -0.061  | 1.027          | 0.033            | 0.010     |
Table 8. Cont.

| Variables | Living Status | Rely On | Social Activity | Station Distance | Frequency |
|-----------|---------------|---------|-----------------|------------------|-----------|
| AVs       |               |         |                 |                  |           |
| PU        | 0.044         | 0.028 **| 0.099           | 0.005*           | 0.018     |
| PE        | 0.107         | −0.937  | 0.012           | 0.046            | −0.044    |
| AT        | 0.028         | 0.011 * | 0.225           | 0.119            | 0.006     |
| SWB       | 0.003         | 0.050   | 0.100           | 0.260            | 0.057 **  |
| SI        | 0.083         | −0.228  | 0.147 **        | 0.007            | 0.050     |
| SAVs      |               |         |                 |                  |           |
| PU        | −0.009        | 0.105 * | 0.339           | 1.005            | −0.032    |
| PE        | 0.201         | −0.016  | 0.060           | 0.049            | 0.030     |
| AT        | 0.018 *       | 0.499   | 0.247           | 0.020            | −0.011    |
| SWB       | −0.056        | 0.070   | 0.023           | 0.177            | 0.409     |
| SI        | 0.037         | 0.002   | 0.021 **        | 0.204            | 0.032     |

Note: *: \( p < 0.05 \); **: \( p < 0.01 \).

Table 7 shows the effects of personal factors on latent variables. In the MIMIC model of the elderly’s travel patterns, not all observed variables have significant effects on latent variables. Overall, the physical health of the elderly has a significant impact on most latent variables; mental health has a significant effect on latent variables in models for public transport and AVs; age and license are significantly related to individual latent factors for three modes. The three variables of gender, education, and income have a conspicuous influence on latent variables in the MIMIC model of the AVs and SAVs. It is worth noting that career only affects latent variables in the AVs model.

Table 8 shows the influence of personal characteristics and social factors on the latent variables. The following is the discussion of each observed variable.

(1) Social factors: The living status variable showed a significant positive correlation for perceived usefulness and attitude in the MIMIC models of AVs and SAVs, respectively. Whether to rely on others for daily travel has a significant correlation with perceived usefulness in the MIMIC models of AVs and SAVs, indicating the diversification and convenience of elderly people who depend on others to travel. Besides, this variable plays a positive role in the attitude of the AVs model. The frequency of participation in social activities has a positive impact on the social impact in the MIMIC model of AVs and SAVs, implying that older people often participate in social activities and are exposed to other people’s perceptions of travel modes, which affect their mode choice pattern, especially for emerging modes. The elderly will share with and influence each other before using emerging travel mode.

(2) Travel attributes: The variable of station distance negatively correlates with perceived usefulness and perceived ease of use in the MIMIC model for public transport, which indicates that the further the bus stop is from home, the less likely the elderly will use the bus. Station distance has a positive correlation with perceived usefulness in AVs. When the bus station is far away, the AVs will meet their travel needs and improve travel convenience. The variable of the frequency of using buses has played a positive role in the perceived usefulness and attitude in the MIMIC model for public transport, showing that the higher the frequency of using the bus, the more positive they are likely to travel. It also has a significant positive impact on AVs’ SWB, which may be due to the fatigue of the elderly who use buses often, and they may prefer a comfortable and free way of travel.

5.4.3. The Relationship between Latent Variables

We apply MIMIC models to analyze choice behavior among three travel modes: public transport, the AVs, and SAVs. The path relations among the constructs in the MIMIC models for different modes are shown in Figures 5–7. The value in parentheses is the \( z \)-value, and the * on the numerical superscript indicates the degree of significance (** means \( p < 0.001 \), * means \( p < 0.01 \), * means \( p < 0.05 \)). \( R^2 \) indicates the MIMIC coefficient’s judgment to predict the elderly’s intention to choose a specific
mode. The goodness of fit based on model construction is good. We present the model estimation results as follows.

![Figure 5](image-url) **Figure 5.** Standardized path coefficients between latent variables for public transport. Note: *: p < 0.05; **: p < 0.01; ***: p < 0.001.

![Figure 6](image-url) **Figure 6.** Standardized path coefficients between latent variables for AVs. Note: *: p < 0.05; **: p < 0.01; ***: p < 0.001.

![Figure 7](image-url) **Figure 7.** Standardized path coefficients between latent variables for SAVs. Note: *: p < 0.05; **: p < 0.01; ***: p < 0.001.

(1) In the MIMIC model, the variance of intention interpretation for the choice intention of the public transport, AVs, and SAVs was 74, 71, and 75%, respectively, which indicates that the extended ecological model has a relatively high explanatory power for the elderly.

(2) Perceived usefulness has a significant positive impact on attitude, with standardized path coefficients of 0.43 (p < 0.01), 0.32 (p < 0.01), and 0.09 (p < 0.05) for public transport, AVs, and SAVs, respectively. Perceived ease of use also showed a significant positive impact on attitude, with standardized path coefficients of 0.64 (p < 0.001), 0.53 (p < 0.01), and 0.44 (p < 0.01). The model results indicate that the elderly are concerned with whether an emerging mode is easy to operate, which will affect their attitude towards travel behavior, thus supporting hypothesis 1. The figures above show that attitude positively influences behavioral intention, which is significant for AVs with the standardized path coefficient 0.51 (p < 0.01), so hypothesis 3 is proved.
(3) We can see from Figures 5–7 that SWB has a significant positive correlation with behavioral intentions, the standardized path coefficient for the AVs is 0.47 \((p < 0.001)\), indicating that AVs can make the elderly experience happiness when their travel demand satisfaction. Therefore, hypothesis 4 proposed above is verified. Attitude also plays a significant positive correlation with SWB, implying that the subjective attitude of the elderly is closely related to their happiness in later life. Perceived ease of use for SWB shows a significant positive correlation. In the model of the SAVs, the standardized path coefficient is 0.53 \((p < 0.001)\), indicating that the ease of use of travel mode has an impact on the mood of the elderly and indirectly affects the intention to use, thus supporting hypothesis 5.

(4) Social influence shows a positive correlation with behavioral intentions in the three models, with path coefficients of 0.35 \((p < 0.05)\), 0.39 \((p < 0.001)\), and 0.54 \((p < 0.01)\), respectively. It presents that the elderly’s travel behavior is affected by the social network and people’s behaviors and attitudes, thus verifying hypothesis 6.

(5) As shown in Table 9, when we remove the perceived usefulness in all three structural equation models, the perceived ease of use has significantly increased the normalized path coefficient and \(z\)-value of behavioral intention. This shows that the existence of perceived usefulness weakens the direct impact of perceived ease of use on behavioral intention, thus supporting hypothesis 2—PU plays a mediating role between PE and AT in the elderly’s mode choice behavior. Similarly, in the absence of attitudes, the role of social influence on behavioral intentions increases significantly, indicating that attitudes share the direct effect of the social influence on the behavioral intentions. Therefore, hypothesis 7 can be verified.

### Table 9. Mediation variable.

| Mediating Variable | Public Transport | AVs | SAVs |
|--------------------|------------------|-----|------|
| The mediating effect of the PU between PE and AT | | | |
| PU (included) | 0.64 *** (10.41) | 0.53 ** (5.32) | 0.44 ** (4.76) |
| PU (excluded) | 0.79 *** (16.94) | 0.69 ** (11.05) | 0.61 ** (8.23) |
| The mediating effect of the AT between SI and BI | | | |
| AT (included) | 0.35 * (5.27) | 0.39 *** (5.13) | 0.54 ** (7.05) |
| AT (excluded) | 0.59 * (9.14) | 0.62 *** (12.70) | 0.73 ** (14.09) |

Note: *: \(p < 0.05\); **: \(p < 0.01\); ***: \(p < 0.001\).

#### 5.5. A Generalized RRM Model (G-RRM)

5.5.1. Parameter Calibration and Model Estimation

Before setting up the G-RRM model, we sorted out the data of travel attributes in the questionnaire. The values of travel time, travel variability time, and travel costs were all taken the unit value according to the scenario’s situation. The following rules apply to the value of the travel comfort: “0” indicates the comfort seat of AVs and SAVs; “1” implies the “front seat” of the bus; “2” represents the “back seat” of the bus; “3” labels the “station” of the bus, as shown in Table 10.

### Table 10. Travel attribute variables.

| Modes     | Travel Time | Travel Variability Time | Travel Cost | Travel Comfort |
|-----------|-------------|------------------------|-------------|---------------|
| Public Transport | 30          | 8                      | 1           | 1             |
|            | 45          | 14                     | 2           | 2             |
|            | 60          | 18                     | 3           | 3             |
| AVs       | 10          | 2                      | 20          | 0             |
|            | 20          | 5                      | 25          | 0             |
|            | 34          | 8                      | 35          | 0             |
| SAVs      | 15          | 5                      | 15          | 0             |
|            | 25          | 10                     | 20          | 0             |
|            | 40          | 15                     | 30          | 0             |
The value of the travel attributes is encoded and replaced in the G-RRM model. The weights of each travel attributes can be normalized to obtain the standardized coefficients, as Table 11 shows.

### Table 11. Travel attributes weights for the elderly.

| Indicators                  | Travel Time | Travel Variability Time | Travel Cost | Travel Comfort |
|-----------------------------|-------------|-------------------------|-------------|---------------|
| Weights                     | 3.59        | 3.51                    | 3.75        | 3.82          |
| Normalized coefficients     | 0.247       | 0.244                   | 0.254       | 0.255         |

We could infer from Figure 8 that the elderly attach the highest importance to travel comfort, followed by travel cost, travel time, and travel variability time related to the elderly’s leisure time after retirement.

![Figure 8. Standardized weight values.](image)

To better reflect the explanatory strength and applicability of the G-RRM model for the travel attributes of the elderly, we also estimate the RUM model. Table 12 compares the results of the two models.

### Table 12. Parameter estimation of elderly travel attribute variables.

| Variables                  | G-RRM | RUM |
|----------------------------|-------|-----|
|                            | Parameter Estimation | t-Test  | Parameter Estimation | t-Test |
| Travel time                | −0.0194 | −4.83 ** | −0.0465 | −4.92 ** |
| Travel variability time    | −0.0325 | −5.61 ** | −0.0650 | −5.64 ** |
| Travel cost                | −0.0169 | −2.37 ** | −0.0329 | −2.32 ** |
| Travel comfort             | −0.0083 | −1.96 ** | −0.0167 | −2.08 ** |
| Samples                    | 1314   | 1314 |
| $LL(\beta)$               | −2,283,143 | −2,314,908 |
| $LL(0)$                    | −3,926,427 | −3,970,683 |
| $\rho^2$                   | 0.425  | 0.417 |

Note: **: $p < 0.01$.

In the questionnaire, the elderly need to choose one of three scenarios. The sample size was 438, so the model’s final sample size was 1314 ($438 \times 3 = 1314$). The four travel attribute variables significantly affect the elderly’s choice behavior, implying that the model has high explanatory power and credibility. $LL(0)$ represents the logarithmic likelihood estimation value with parameter 0. $LL(\beta)$ represents the logarithmic likelihood estimate with parameter $\beta$. $\rho^2$ represents the model’s fitting degree. Both models’ fitting effect is greater than 0.4, indicating that the model fitting effect is good.
When the parameter is $\beta$, the $LL(\beta)$ of the G-RRM model is larger than that of the RUM model. The fit of the G-RRM model is 0.425, while that of the RUM model is 0.417. Therefore, the G-RRM model may be more suitable for analyzing travel attribute variables’ influence on the elderly’s travel behavior.

As can be seen from Table 12, the maximum estimated coefficients are travel comfort, indicating that the elderly are concerned about comfort during the travel. The emergence of AVs and SAVs can provide a comfortable travel environment for the elderly and meet their travel needs. Travel cost has a significantly negative effect on the elderly’s mode choice behavior, which means that the sensitivity for the travel fare is relatively high. Travel time and travel variability time are also significantly correlated with the travel behavior of the elderly because too long travel time will lead to the elderly’s fatigue, thus reducing the possibility of choosing the mode. Since the travel process is dynamic, human and road factors will make travel time changes. The arrival of AVs may bring about a qualitative change in the accessibility of the entire transportation system.

5.5.2. Sensitivity Analysis

The sensitivity analysis is to obtain the corresponding change of the probability of the elderly for a specific travel mode when the attribute changes and can also be viewed as the elasticity value corresponding to the G-RRM model. Sensitivity analysis is usually carried out through direct elasticity and indirect elasticity. Direct elasticity refers to the change of the choice probability of the selected travel mode when a particular travel attribute changes by 1%. We analyze the estimated results through direct elasticity and indirect elasticity, as shown in Table 13.

| Selected Modes | Direct Elasticity | Unselected Modes | Indirect Elasticity |
|----------------|-------------------|------------------|---------------------|
|                | Travel Time       | Travel Variability Time | Travel Cost | Travel Comfort | Travel Time | Travel Variability Time | Travel Cost | Travel Comfort |
| Public transport | -0.201          | -0.174           | -0.421     | 0.927         | AVs   | 0.090 | 0.089 | 0.210 | -0.461 |
| AVs            | -0.217          | -0.192           | -0.475     | 0.948         | SAVs  | 0.097 | 0.082 | 0.217 | -0.469 |
| SAVs           | -0.208          | -0.187           | -0.468     | 0.935         | Public transport | 0.102 | 0.091 | 0.224 | -0.472 |
|                |                  |                  |           |              | SAVs  | 0.113 | 0.098 | 0.239 | -0.479 |
|                |                  |                  |           |              | Public transport | 0.102 | 0.087 | 0.224 | -0.468 |
|                |                  |                  |           |              | AVs   | 0.110 | 0.090 | 0.230 | -0.462 |

Take the travel time as an example to understand the elastic value in the above table. When bus travel time increases by 1%, travelers’ choice probability of bus decreases by 0.201%. When AVs and SAVs’ travel time increase by 1%, respectively, the probability of choosing buses increases by 0.090% and 0.097%, respectively. It can be seen that the elderly are the most sensitive to changes in travel comfort, especially for the AVs. When the travel comfort increases by 1%, the probability of the elderly choosing AVs will increase by 0.948%. However, when buses and SAVs’ travel comfort increase by 1%, the probability of the elderly choosing AVs decreases by 0.472% and 0.479%, respectively. Similarly, the sensitivity of the elderly to travel time and travel variability time is not very high.

6. Limitations and Conclusions

Some limitations need to be resolved in our future work. Firstly, we analyze the elderly’s mode choice behavior among three modes: public transport, AVs, and SAVs. Although less than 3% of the elderly in China drive [5], we could predict that the percentage of driving for the elderly would increase sharply due to the elderly’ license with no age limitation and growth in the living standard. Therefore, we will introduce driving into our research and explore the potential constructs affecting the elderly’s driving behavior in the future study. Secondly, most participants did not ride AVs and had no field experience with AVs’ benefits or drawbacks. The participants’ knowledge concerning
AVs from the internet and other channels may mislead their perspectives or attitudes. In our future research, we will use a video or AVs’ simulator to make the participants have a more real feeling for AVs. Thirdly, the research sample comes from Suzhou survey data, and the result may not be generalizable to the entire population. We may pay attention to the difference among various regions for the elderly’s travel behavior.

Based on the elderly’s travel needs and the extended ecological model, we analyze the mode choice behaviors of the elderly towards public transport, AVs, and SAVs in the future. The research conclusions are as follows:

(1) We integrate the relevant factors that affect the travel of the elderly and expand the ecological model by introducing the constructs, which provide a theoretical framework for the elderly. Moreover, we analyze the modeling results of empirical data and verify the theoretical framework’s applicability to the elderly’s travel behavior.

(2) The MIMIC model is used to analyze the relationship between the extended latent variables and the original observed variables of the ecological model. We can see that the observed variables have different degrees of influence on the constructs in the MIMIC model for public transport, AVs, and SAVs. The interaction and internal mechanism of expanded constructs were analyzed with the MIMIC model. Seven hypotheses proposed in this paper were proved to understand the elderly’s travel psychology.

(3) Through the analysis and discussion of relevant influencing factors, we can have a deeper understanding of the views and acceptability of the elderly towards AVs and SAVs. Given the psychological characteristics and elderly’s behaviors, enterprises can develop corresponding AVs to better meet and serve the travel needs in the future.

We also proposed practical suggestions according to our research results.

(1) We suggest that the local government could make policies or measures to create a good living environment and safeguard the elderly’s physical health, which significantly influences their attitude towards AVs and SAVs. In other words, policies concerning the elderly’s physical health have a potential opportunity to increase their acceptance of AVs and SAVs.

(2) SWB has a significant positive correlation with BI. We advise enterprises to install an entertainment system with a large screen, making the elderly enjoy leisure and happiness, which could improve their SWB during the travel in AVs and SAVs.

(3) Travel variability time is significantly correlated with the travel behavior of the elderly. To improve travel time reliability and decrease the elderly’s travel variability time, we suggested that the public transport agencies could improve bus system efficiency, such as optimizing bus routes net, increasing departure frequency, and reducing waiting time.

In our study, PU refers to the degree to which the elderly believe that using a transport mode would enhance their travel performance. Meanwhile, PE indicates the degree to which the elderly believe that using public transport, AVs, and SAVs would be free of physical and mental effort. The study results show that PU and PE significantly impact attitude for the three travel modes, and PU influences BI significantly for SAVs. To accelerate the extensive application of AVs and SAVs for the elderly, the enterprises could install a small slide and provide enough space to help disabled elderly get on or off to improve their PU and PE.

Author Contributions: Writing and editing—original draft preparation, H.S.; conceptualization and supervision, funding acquisition, P.J.; data analysis, M.Z. and Y.C.; validation and literature review, F.Z. and Y.S. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the National Natural Science Foundation of China (Grant No. 71871107).

Conflicts of Interest: The authors declare no conflict of interest.
**Glossary**

- AVs  Autonomous Vehicles
- SAVs  Shared Autonomous Vehicles
- TAM  Technology Acceptance Model
- PU  Perceived Usefulness
- PE  Perceived Ease of use
- PC  Perceived Characteristics
- AT  Attitude
- BI  Behavioral Intention
- SWB  Subjective Well-Being
- SN  Social Network
- SI  Social Influence
- MIMIC  Multiple Indicators and Multiple Causes
- G-RRM  Generalized Random Regret Minimization Model
- RRM  Random Regret Minimization Model
- CFI  Comparative Fit Index
- TLI  Tucker-Lewis Index
- RMSEA  Root Mean Squared Error of Approximation
- SRMR  Standardized Root Mean Squared Residual
- AVE  Average Variance Extracted

**References**

1. Wong, R.C.P.; Szeto, W.Y.; Yang, L.; Li, Y.C.; Wong, S.C. Public transport policy measures for improving elderly mobility. *Transp. Policy* 2018, 63, 73–79. [CrossRef]
2. Banister, D.; Bowling, A. Quality of life for the elderly: The transport dimension. *Transp. Policy* 2004, 11, 105–115. [CrossRef]
3. Newbold, K.B.; Scott, D.M.; Spinney, J.E.L.; Kanaroglou, P.; Páez, A. Travel behavior within Canada’s older population: A cohort analysis. *J. Transp. Geogr.* 2005, 13, 340–351. [CrossRef]
4. Olawole, M.O.; Aloba, O. Mobility characteristics of the elderly and their associated level of satisfaction with transport services in Osogbo, Southwestern Nigeria. *Transp. Policy* 2014, 35, 105–116. [CrossRef]
5. Hu, X.; Wang, J.; Wang, L. Understanding the travel behavior of elderly people in the developing country: A case study of changchun, China. *Procedia Soc. Behav. Sci.* 2013, 96, 873–880. [CrossRef]
6. Boschmann, E.E.; Brady, S.A. Travel behaviors, sustainable mobility, and transit-oriented developments: A travel counts analysis of older adults in the Denver, Colorado metropolitan area. *J. Transp. Geogr.* 2013, 33, 1–11. [CrossRef]
7. Muhammad, T.; Kashmiri, F.A.; Naem, H.; Qi, X.; Chia-Chun, H.; Lu, H. Simulation study of autonomous vehicles’ effect on traffic flow characteristics including autonomous buses. *J. Adv. Transp.* 2020, 2020, 1–17. [CrossRef]
8. Harper, C.D.; Hendrickson, C.T.; Mangones, S.; Samaras, C. Estimating potential increases in travel with autonomous vehicles for the non-driving, elderly and people with travel-restrictive medical conditions. *Transp. Res. Part. C Emerg. Technol.* 2016, 72, 1–9. [CrossRef]
9. Tan, L.; Ma, C.; Xu, X.; Xu, J. Choice behavior of autonomous vehicles based on logistic models. *Sustainability*. 2020, 12, 54. [CrossRef]
10. Nuzzolo, A.; Persia, L.; Comi, A.; Polimeni, A. Shared autonomous electrical vehicles and urban mobility: A vision for rome in 2035. In *Data Analytics: Paving the Way to Sustainable Urban Mobility*, Nathanail, E.G., Karakikes, I.D., Eds.; Springer International Publishing: Berlin/Heidelberg, Germany, 2019; pp. 772–779. [CrossRef]
11. Tan, W.-K.; Lin, C.-Y. Driverless car rental at tourist destinations: From the tourists’ perspective. *Asia Pac. J. Tour. Res.* 2020, 25, 1153–1167. [CrossRef]
12. Liu, P.; Ma, Y.; Zuo, Y. Self-driving vehicles: Are people willing to trade risks for environmental benefits? *Transp. Res. Part. A Policy Pract.* 2019, 125, 139–149. [CrossRef]
13. Moreno, A.T.; Michalski, A.; Llorca, C.; Moockel, R. Shared autonomous vehicles effect on vehicle-Km traveled and average trip duration. *J. Adv. Transp.* 2018, 2018, 1–10. [CrossRef]
14. Asmussen, K.E.; Mondal, A.; Bhat, C.R. A socio-technical model of autonomous vehicle adoption using ranked choice stated preference data. *Transp. Res. Part C Emerg. Technol.* 2020, 121, 102835. [CrossRef]

15. Menon, N.; Barbour, N.; Zhang, Y.; Pinjari, A.R.; Mannering, F. Shared autonomous vehicles and their potential impacts on household vehicle ownership: An exploratory empirical assessment. *Int. J. Sustain. Transp.* 2019, 13, 111–122. [CrossRef]

16. Levin, M.W.; Boyles, S.D. Effects of autonomous vehicle ownership on trip, mode, and route choice. *Transp. Res. Rec.* 2015, 2493, 29–38. [CrossRef]

17. Hough, J.A.; Cao, X.; Handy, S.L. Exploring travel behavior of elderly women in rural and small urban North Dakota: An ecological modeling approach. *Transp. Res. Rec.* 2008, 2082, 125–131. [CrossRef]

18. Mifsud, D.; Attard, M.; Ison, S. To drive or to use the bus? An exploratory study of older people in Malta. *J. Transp. Geogr.* 2017, 64, 23–32. [CrossRef]

19. Truong, L.T.; Somenahalli, S.V.C. Exploring frequency of public transport use among older adults: A study in Adelaide, Australia. *Travel Behav. Soc.* 2015, 2, 148–155. [CrossRef]

20. Feng, J. The influence of built environment on travel behavior of the elderly in urban China. *Transp. Res. Part D Transp. Environ.* 2017, 52, 619–633. [CrossRef]

21. Srnetzer, S.R. Constraints on Elderly Daily Travel Behaviour. Ph.D. Thesis, The University of Western Ontario, London, ON, Canada, 1997.

22. Payyanadan, R.P.; Lee, J.D. Understanding the ridesharing needs of older adults. *Travel Behav. Soc.* 2018, 13, 155–164. [CrossRef]

23. Schmöcker, J.-D.; Quddus, M.A.; Noland, R.B.; Bell, M.G.H. Mode choice of older and disabled people: A case study of shopping trips in London. *J. Transp. Geogr.* 2008, 16, 257–267. [CrossRef]

24. Amen, P.A.M.V. Exploring Elderly Mobility in the Greater Rotterdam Area: Assessing the Influence of Personal Characteristics and Weather Conditions on Mode Choice & the Number of Trips. Master’s Thesis, Faculty of Geosciences Theses, Utrecht University, Utrecht, The Netherlands, 2014.

25. Rahman, M.M.; Strawderman, L.; Adams-Price, C.; Turner, J.J. Transportation alternative preferences of the aging population. *Travel Behav. Soc.* 2016, 4, 22–28. [CrossRef]

26. Liu, S.; Chen, W.; Chi, Q.; Yan, H. Comparison of the elderly travel behavior in the south and the north of China. *J. Guizhou Univ. (Nat. Sci.).* 2016, 33, 604–608. [CrossRef]

27. Haboucha, C.J.; Ishaq, R.; Shiftan, Y. User preferences regarding autonomous vehicles. *Transp. Res. Part C Emerg. Technol.* 2017, 78, 37–49. [CrossRef]

28. LaMondia, J.J.; Fagnant, D.J.; Qu, H.; Barrett, J.; Kockelman, K. Shifts in long-distance travel mode due to automated vehicles: Statewide mode-shift simulation experiment and travel survey analysis. *Transp. Res. Rec.* 2016, 2566, 1–11. [CrossRef]

29. Yap, M.D.; Correia, G.; van Arem, B. Preferences of travellers for using automated vehicles as last mile public transport of multimodal train trips. *Transp. Res. Part A Policy Pract.* 2016, 94, 1–16. [CrossRef]

30. Liu, D.; Du, H.; Southworth, F.; Ma, S. The influence of social-psychological factors on the intention to choose low-carbon travel modes in Tianjin, China. *Transp. Res. Part A Policy Pract.* 2017, 105, 42–53. [CrossRef]

31. Nazari, F.; Noruzolaiae, M.; Mohammadian, A.K. Shared versus private mobility: Modeling public interest in autonomous vehicles accounting for latent attitudes. *Transp. Res. Part C Emerg. Technol.* 2018, 97, 456–477. [CrossRef]

32. Pakusch, C.; Stevens, G.; Boden, A.; Bossauer, P. Unintended effects of autonomous driving: A study on mobility preferences in the future. *Sustainability* 2018, 10. [CrossRef]

33. Pettigrew, S.; Dana, L.M.; Norman, R. Clusters of potential autonomous vehicles users according to propensity to use individual versus shared vehicles. *Transp. Policy* 2019, 76, 13–20. [CrossRef]

34. Acheampong, R.A.; Cugurullo, F. Capturing the behavioural determinants behind the adoption of autonomous vehicles: Conceptual frameworks and measurement models to predict public transport, sharing and ownership trends of self-driving cars. *Transp. Res. B.* 2019, 121, 349–375. [CrossRef]

35. Davey, J.A. Older people and transport: Coping without a car. *Ageing Soc.* 2007, 27, 49–65. [CrossRef]

36. Shergold, I. Taking part in activities, an exploration of the role of discretionary travel in older people’s wellbeing. *J. Transp. Health* 2019, 12, 195–205. [CrossRef]
38. Krueger, R.; Rashidi, T.H.; Rose, J.M. Preferences for shared autonomous vehicles. *Transp. Res. Part C Emerg. Technol.* 2016, 69, 343–355. [CrossRef]
39. Davis, F.D. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q.* 1989, 13, 319–340. [CrossRef]
40. Zhang, T.; Tao, D.; Qu, X.; Zhang, X.; Lin, R.; Zhang, W. The roles of initial trust and perceived risk in public’s acceptance of automated vehicles. *Transp. Res. Part C Emerg. Technol.* 2019, 98, 207–220. [CrossRef]
41. Panagiotopoulos, I.; Dimitrakopoulos, G. An empirical investigation on consumers’ intentions towards autonomous driving. *Transp. Res. Part C Emerg. Technol.* 2018, 95, 773–784. [CrossRef]
42. Bergstad, C.J.; Gamble, A.; Gärling, T.; Hagman, O.; Polk, M.; Ettema, D.; Olsson, L.E. Subjective well-being related to satisfaction with daily travel. *Transportation* 2011, 38, 1–15. [CrossRef]
43. Chen, X.; Li, X.; Zhu, H. Condition evaluation of urban metro shield tunnels in Shanghai through multiple indicators multiple causes model combined with multiple regression method. *Tunn. Undergr. Space Technol.* 2019, 85, 170–181. [CrossRef]
44. Levy, H. Regret theory: State dominance and expected utility. *J. Math. Psychol.* 2017, 79, 1–12. [CrossRef]
45. Loomes, G.; Sugden, R. Regret theory: An alternative theory of rational choice under uncertainty. *Econ. J.* 1982, 92, 805–824. [CrossRef]
46. Chorus, C.G. A generalized random regret minimization model. *Transp. Res. Part B Methodol.* 2014, 68, 224–238. [CrossRef]
47. Ma, L.; Zhang, X.; Ding, X.; Wang, G. Bike sharing and users’ subjective well-being: An empirical study in China. *Transp. Res. Part A Policy Pract.* 2018, 118, 14–24. [CrossRef]
48. Watts, D.J. Networks, dynamics, and the small-world phenomenon. *Am. J. Sociol.* 1999, 105, 493–527. [CrossRef]
49. Montazemi, A.R.; Conrath, D.W. The use of cognitive mapping for information requirements analysis. *MIS Q.* 1986, 10, 45–56. [CrossRef]
50. Kim, J.; Rasouli, S.; Timmermans, H.J. Investigating heterogeneity in social influence by social distance in car-sharing decisions under uncertainty: A regret-minimizing hybrid choice model framework based on sequential stated adaptation experiments. *Transp. Res. Part C Emerg. Technol.* 2017, 85, 47–63. [CrossRef]
51. Davis, F.D. User acceptance of information technology: System characteristics, user perceptions and behavioral impacts. *Int. J. Man-Machine Stud.* 1993, 38, 475–487. [CrossRef]
52. Chen, C.-F.; Chao, W.-H. Habitual or reasoned? Using the theory of planned behavior, technology acceptance model, and habit to examine switching intentions toward public transit. *Transp. Res. Part F Traffic Psychol. Behav.* 2011, 14, 128–137. [CrossRef]
53. Chen, S.-Y. Using the sustainable modified TAM and TPB to analyze the effects of perceived green value on loyalty to a public bike system. *Transp. Res. Part A Policy Pract.* 2016, 88, 58–72. [CrossRef]
54. Liu, J.; Kockelman, K.M.; Boesch, P.M.; Ciari, F. Tracking a system of shared autonomous vehicles across the Austin, Texas network using agent-based simulation. *Transportation* 2017, 44, 1–18. [CrossRef]
55. Stark, J.; Hössinger, R. Attitudes and mode choice: Measurement and evaluation of interrelation. *Transp. Res. Procedia* 2018, 32, 501–512. [CrossRef]
56. Kim, M.J.; Lee, C.-K.; Preis, M.W. The impact of innovation and gratification on authentic experience, subjective well-being, and behavioral intention in tourism virtual reality: The moderating role of technology readiness. *Telinat. Inform.* 2020, 49, 101349. [CrossRef]
57. Adam, Z.; Walasek, L.; Meyer, C. Workforce commuting and subjective well-being. *Travel Behav. Soc.* 2018, 13, 183–196. [CrossRef]
58. Ajzen, I.; Fishbein, M. *Understanding Attitudes and Predicting Social Behavior*, Prentice-Hall: Englewood Cliffs, NJ, USA, 1980.
59. Bagozzi, R.P. Evaluating structural equation models with unobservable variables and measurement error: A Comment. *J. Mark. Res.* 1981, 18, 375–381. [CrossRef]