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Preferences Regarding Parking and Sharing Use for Privately Owned Autonomous Vehicles Based on a Virtual-Actual Experience

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ABSTRACT

Autonomous vehicles are capable of automatically cruising and parking, presenting an opportunity for these vehicles to be shared with others during idle periods. This study conducted a face to face stated preference survey on parking and shared use of privately owned autonomous vehicles based on a virtual-actual experience in Beijing. Utilizing 232 valid samples, a nested Logit model was established to analyse the hierarchical choice behaviour regarding parking modes, parking locations and shared use of autonomous vehicles. The research results show that travellers with a favourable initial understanding of autonomous vehicles and a significantly improved perception of them after the travel experience are more likely to choose the parking mode of 'Platform agency (parking + paid sharing)'. Travellers tend to prefer remote parking places that offer lower parking fees and higher reliability in vehicle retrieval when needed. Additionally, travellers are more inclined to share their autonomous vehicles when the vehicle-sharing service platform offers lower agency fees and higher sharing earnings and allows temporary vehicle retrieval. Increasing public sharing attitude and perception of autonomous vehicles through travel experiences and advertising can encourage more people to accept car sharing. These findings offer key insights into the factors that affect the market penetration of private vehicle-sharing services in future.

KEYWORDS

autonomous vehicles; virtual-actual experience; remote parking; vehicle sharing.

1. INTRODUCTION

With the rapid development of new technology, the emergence of autonomous vehicles (AVs) has brought new transformations to transportation systems [1–2]. Compared to traditional cars, autonomous vehicles have the ability to automatically find a parking space and park themselves. This means that travellers do not need to drive to the parking lot to park their vehicles or walk to the parking lot to retrieve them. As shown in *Figure 1*, autonomous vehicles are not constrained by the need for traditional close parking near the destination. They can automatically perform remote parking or return home to park until users need it again, thus avoiding high parking fees near destinations [3–4]. Therefore, the automatic cruise and remote parking capabilities of autonomous vehicles can reduce parking demand in urban centres, freeing up a significant number of parking facilities and increasing urban land use space.

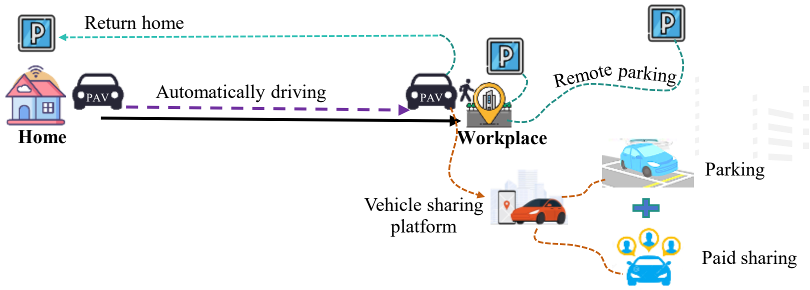


Figure 1 – Schematic diagram of parking and shared use for autonomous vehicles

In addition, the self-driving capability of autonomous vehicles enables them to navigate independently to designated locations, offering significant convenience for owners to share their idle autonomous vehicles with others for compensation. In recent years, vehicle sharing has received widespread attention and many enterprises have launched sharing projects. For example, China's shared bicycles, cars and other similar services provide convenient transportation options for citizens. Some private vehicle-sharing platforms, such as Turo and Getaround, already enable traditional private car owners to rent out their idle cars. These examples demonstrate the enormous potential of the vehicle-sharing rental market. In future transportation systems, it is a promising option to share private autonomous vehicles with others, which can allow car owners to earn extra income, improve resource utilization and enable more efficient traffic operations. Therefore, the shared use of autonomous vehicles will result in broad application prospects in the near future. Research on cruising for parking and shared use of autonomous vehicles is necessary and highly meaningful.

Currently, autonomous vehicles are not widely used in daily life. However, some cities have launched autonomous driving service demonstration areas to allow the public to experience autonomous vehicles. For instance, as the first batch of pilot cities for the construction of high-level autonomous driving service demonstration area in China, Beijing has officially launched robotaxi service, Apollo Go in September 2020. Travellers can make reservations via smartphone apps and experience travel with autonomous vehicles. Feedback from people's travel experiences in demonstration areas can offer valuable insight into their attitudes and perspectives on autonomous vehicles and facilitate further exploration of travel behaviours associated with autonomous vehicles in this study.

Previous research has primarily focused on parking choice behaviour for travel with autonomous vehicles, relying on stated choice experiments or simulation models [5–7]. Some studies have explored travellers' willingness to use on-demand public services, known as Shared Autonomous Vehicles (SAVs) [8–10]. However, less attention has been given to the shared use of privately owned autonomous vehicles during idle periods [11]. This study primarily addresses two research questions: how to obtain more realistic and reliable data regarding parking and shared use intention with autonomous vehicles due to their limited access in daily life and how to conduct a comprehensive analysis of hierarchical choice behaviours, and underlying internal and external determinants. Therefore we elaborately designed a parking and shared use survey based on participants' virtual-actual travel and parking experiences with autonomous vehicles. A Nested Logit model was constructed to explore travellers' hierarchical choice behaviours regarding parking mode, parking location and shared use of autonomous vehicles. Nested Logit model offers significant methodological advantages by relaxing the independence of irrelevant alternatives (IIA) assumption inherent in multinomial logit models. The hierarchical choice framework was developed with partial reference to existing literatures [12–13] and conventional vehicle-sharing platforms. Through sensitivity analysis, the effects of parking, paid sharing and travel experience-related factors on shared use choice behaviours for autonomous vehicles were comprehensively analysed. These research findings can provide valuable references for the exploratory application of sharing services for autonomous vehicles in future transportation systems. Additionally, they can offer suggestions for guiding the formulation of parking policies.

The structure of this paper is as follows. Section 2 reviews the existing literature. Section 3 introduces a parking and shared use survey and data collection based on the travel experience of autonomous vehicles. Section 4 presents a comprehensive descriptive analysis of the survey data. Section 5 introduces the methodology for the travel behaviour analysis. Section 6 illustrates the model estimation results and analysis of parking and shared use intentions for autonomous vehicles. Finally, Section 7 presents the main findings, limitations and future research.

2. LITERATURE REVIEW

With the continuous growth in car ownership, urban parking problems have become an important issue in the use of cars [14–15]. Many scholars have conducted extensive research on the parking behaviour of traditional car use. They analysed various factors that influence parking location choice [16–17]. Chen et al. [18] applied fuzzy decision-making theory to determine that the key factors affecting travellers' parking choices include parking distance from the destination, walking distance after parking and available parking spaces. Li et al. and Hassine et al. [19–20] used a discrete choice framework to investigate parking choice behaviour. Their results showed that parking fees, cruising time and walking distance after parking have an impact on parking choices.

In recent years, with the rapid advancement of autonomous driving technology, some scholars have progressively delved into research on parking issues in autonomous vehicles [21–22]. For instance, Millard-Ball [23] analysed parking choices involving travel with autonomous vehicles. Their research revealed that almost 40% of travellers are still inclined to park close to their destination, and nearly 39% choose to continue cruising rather than parking. Bahrami and Roorda [5] studied parking decisions of autonomous vehicle users using an agent-based simulation model. These results indicate that parking fees are still the primary determinant of parking decisions. Travellers are more inclined to park their cars at home or cruise around rather than utilize paid parking lots. Tian et al. [6] conducted a stated choice experiment to investigate the parking choice behaviour of autonomous vehicles. Their research revealed that the effect of parking fees on parking location choices is larger than that of congestion and access times. From the literature above, it is evident that the parking behaviour of autonomous vehicle users differs from that of traditional car owners in terms of parking location choice and influencing factors. Consequently, it is necessary to conduct in-depth research to support the development of effective parking policies and traffic planning in the era of autonomous vehicles.

As we know, the shared use of vehicles can reduce the number of automobiles and parking demand, thereby mitigating traffic congestion and environmental pollution. The common sharing service mode is for companies to purchase their own cars and provide public rental and use services. The research by Dias et al. [24] utilized a bivariate ordered probit model to explore the individual differences in the usage frequency of car-sharing services. The results showed that young, highly educated, high-income and employed individuals are more likely to use car sharing. Paundra et al. [25] conducted an online experiment to investigate travellers' intentions to choose their own car or a shared car provided by an agency. The results suggest that a reduced sense of psychological ownership may increase the preference for shared cars. Tao et al. [26] developed a mixed logit model to indicate that an individual's housing status and income level are important factors in the use of car-sharing services.

In addition to the sharing services of traditional cars, autonomous vehicles are expected to be widely integrated with shared mobility services. Shared autonomous vehicles (SAVs) offer travellers on-demand public services and enable riders to share their travel costs [27]. Related research by Si et al. [8] employed a structural equation model to examine travellers' willingness to use shared autonomous vehicles. The findings revealed that external factors, such as policy support, as well as personal attributes, such as environmental concerns, have an impact on travellers' adoption of shared autonomous vehicles. Lv et al. [28] conducted a study on intention to use an automated car-sharing system based on the theory of planned behaviour. They introduced perceived risk and task-technology matching into the theoretical model and found that these factors provided a more robust explanation of behavioural intention towards an automated car-sharing system. Etminani-Ghasrodashti et al. [9] employed a Technology Acceptance Model to capture the factors influencing the use of shared autonomous vehicles. The results indicated that perceived usefulness and inherent risks significantly influence the adoption of shared autonomous vehicles.

Furthermore, sharing privately owned autonomous vehicles with others through a vehicle-sharing platform would be a promising travel mode in the future. To the authors' knowledge, there are a few related studies on the shared use of private autonomous vehicles during idle parking periods. The related research by Shirley et al. [29] examined individuals' willingness to share their autonomous vehicles temporarily with carless households for evacuation in the face of hurricane threats. The results showed that individuals who were unemployed and more comfortable with autonomous vehicles were more willing to share their vehicles for evacuation. Khayati et al. [11, 30] analysed the travel patterns during the shared use of autonomous vehicles among family members. A mixed-integer programming model was developed to simulate household's travel decision for using an autonomous vehicle. The results indicated that 62% of households can replace two or three conventional vehicles with one autonomous vehicle for their daily activities.

In summary, existing research predominantly employs stated preference data and simulation methods to examine parking choice behaviour and willingness to adopt autonomous vehicles. However, given the limited access to autonomous vehicles, such stated intentions may not accurately reflect actual behavioural choices. First-hand experience with autonomous vehicle can enhance the travellers' understanding of this emerging mode and generate more authentic preference data. While several studies have explored shared autonomous vehicles for on-demand public services, researchers have paid less attention to the potential of sharing privately owned autonomous vehicles with the public during idle periods.

To address these issues, this study aimed to investigate commuters' parking and shared use intentions for privately owned autonomous vehicles based on travel experience. The contributions of this study include: (1) incorporating the factor of shared use while investigating parking issues of privately owned autonomous vehicles by providing a vehicle-sharing service; (2) designing a dynamic virtual cruising and parking experience system – we conducted a parking and shared use survey in Beijing, and collected more realistic preference data based on travel experiences with autonomous vehicles in the field; and (3) incorporating individual perceptions and attitudes – we performed a comprehensive analysis of hierarchical choice behaviour regarding parking modes, parking locations and shared use of privately owned autonomous vehicles. These research findings can provide initial references for parking and shared use behaviour analysis, and guide the formulation of parking policies tailored to the era of travel with autonomous vehicles.

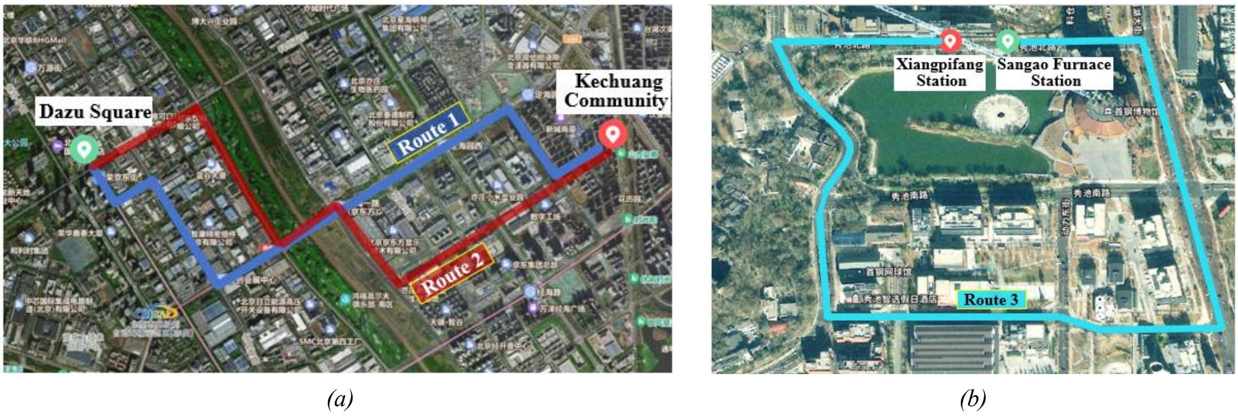
3. SURVEY ON PARKING AND SHARED USE INTENTIONS FOR AUTONOMOUS VEHICLES

3.1 Travel and parking experience regarding autonomous vehicles

Overview of the experience areas and routes

This study selected the Yizhuang and Shougang autonomous driving service demonstration areas in Beijing as the experience locations. The Yizhuang autonomous driving service demonstration area provides four experiential routes. These experience routes are equipped with fixed experience stations for travellers to get on and off. The selected experience route starts from Dazu Square and ends at Kechuang Community, as shown in *Figure 2a.* Outbound Route 1 spans approximately 7.1 kilometres, traversing 22 intersections, whereas return Route 2 is roughly 7.2 kilometres long, including 17 intersections. The average travelling speed of autonomous vehicles along the experience routes during the peak periods is approximately 25 km/h. In the Shougang autonomous driving service, demonstration area is situated within the open 8.6-square-kilometer Shougang Park, the chosen experience route 3 begins at the Sangao Furnace Station and ends at the Xiangpifang Station, covering a total distance of 2.1 kilometres and crossing four intersections along the way, as shown in *Figure 2b*. The average traveling speed on Route 3 is roughly 15km/h.

The autonomous vehicles operating within the two demonstration areas are Baidu's L4 level robotaxis. Travellers can make reservations via smartphone apps, such as "Luobo Kuai Pao" or "Xiaoma Zhi Xing" and experience travel with autonomous vehicles.

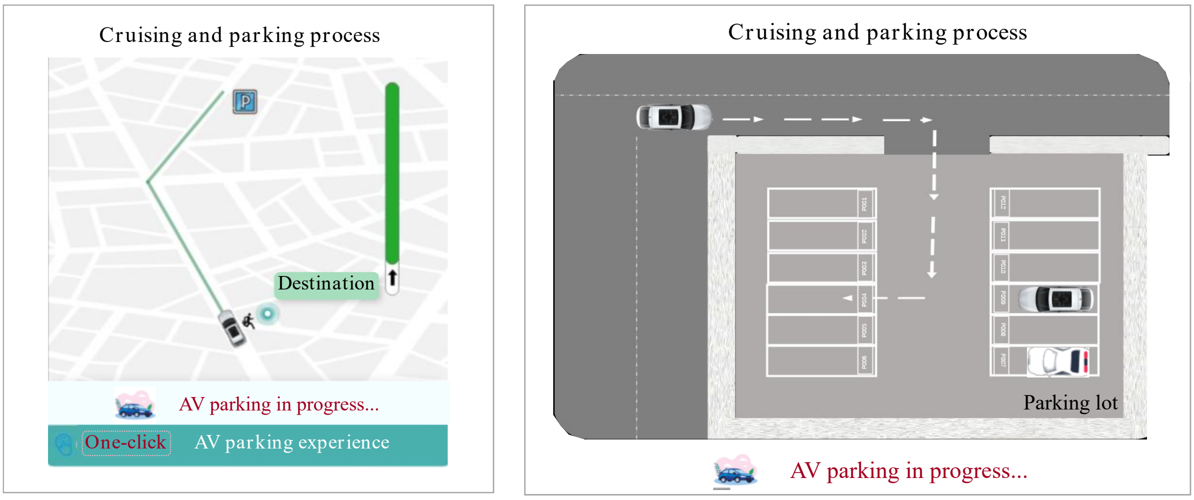


(a) (b)

Figure 2 – The experiential routes and autonomous vehicles: a) Yizhuang; b) Shougang

Design of the dynamic virtual cruising and parking experience system

In autonomous driving service demonstration areas, travellers can experience a travel process with autonomous vehicles. Autonomous vehicles can also automatically cruise to a parking space, drive and park themselves. To enable travellers to experience this self-parking feature, a virtual dynamic system was designed to demonstrate the cruising and parking process of travel with autonomous vehicles. The experiential process includes three parts: selecting a parking lot upon reaching the destination, automatically driving to the parking lot and entering a parking space, as illustrated in *Figure 3*.



(a) (b)

Figure 3 – The interfaces of the dynamic cruising and parking experience system: a) Automatic cruising and driving process; b) Process for entering parking space

The experiential content was designed and transformed into dynamic interfaces using animation software such as Adobe XD and Animate. Dynamic interactive buttons were also incorporated to enhance the realism of the parking experience process. Necessary textual explanations were added to the dynamic interfaces to ease participants' understanding of the parking process using autonomous vehicles. Finally, the virtual dynamic system for the cruising and parking process of autonomous vehicles was disseminated on an Intelligent Surface Tablet and presented to travellers during the travel experience process in autonomous driving service demonstration areas. Participants could fully immerse themselves in travel with autonomous vehicles and gain a comprehensive perception of them.

3.2 Survey on the perceptions and attitudes towards autonomous vehicles

Before the travel experience, participants were required to indicate their initial understanding of autonomous vehicles. The available options include: "I have never followed or heard of AVs."; "I have only heard about AVs through news, internet and other sources."; "I possess a fundamental understanding of the development and functions of AVs."; "I am comparatively well-informed and inclined to personally experience AV travel."; "I have already experienced AV travel."; "I want to purchase and use an AV in my daily travel.". These options are assigned values from 1 to 6 accordingly during the analysis of survey data.

Four distinct aspects were designed both before and after the travel experience to analyse the changes in an individual's perception of autonomous vehicles. The first aspect refers to the travel process using AVs, including factors such as smoothness and flexibility of driving. The second aspect is associated with the feelings of daily use of AVs, encompassing perceived convenience and changes in travel time for travel with AVs. The third aspect is the perceived safety of using AVs in terms of privacy protection and accident liability allocation. The final aspect is the perceived impact of using AVs on road traffic and the environment. First, respondents were asked to rank the four aspects according to their degree of attention, and then provide their perceived evaluations for each aspect using a 7-point scale. The options range from "very poorly known" (1) to "very well known" (7). These four dimensions of questions were incorporated into a questionnaire to be presented before the travel experience, and the same set of questions appeared in a questionnaire administered after the travel experience.

Additionally, after the travel experience, several questions were designed to assess the attitudes of travellers towards autonomous vehicles. The first question relates to the agreement with the statement, “In comparison with traditional cars, an autonomous vehicle does not require drivers for driving, parking and retrieval. What do you think about the convenience of travel?”, with options ranging from “very inconvenient” (1) to “very convenient” (5). The second question inquires about the perception of driving safety of autonomous vehicles, offering a scale from “very unsafe” (1) to “very safe” (5). The third set of questions addresses attitudes towards ownership and the shared use of autonomous vehicles. These include “An autonomous vehicle is simply a means of transportation, intended solely for the convenience of travel.” and “If I owned an autonomous vehicle, I could share it with others for compensation when it is not in use” with options ranging from “strongly disagree” (1) to “strongly agree” (5).

3.3 Survey on parking and shared use intentions regarding autonomous vehicles

To gain a deeper understanding of the travellers’ preferences for travel with autonomous vehicles, we designed a stated choice survey that encompasses a hypothetical commuting scenario, parking and shared use intentions, daily commuting behaviour and personal information. The survey content was transformed into graphical user interfaces using Microsoft Visual Studio to facilitate data collection and improve efficiency. Through software development, it enables multi-level jumping of questions, random presentation of intention scenarios and real-time automatic saving as well as uploading of survey data. Combined with the dynamic cruising and parking experience system, the user interfaces for parking and shared use intentions were also deployed onto the Intelligent Surface Tablet. The touch screen functionality and high-definition display of the Surface Tablet enhance the travellers’ perception of the automatic parking process and facilitate respondents in completing choice questions with high quality.

Design of a hypothetical commuting scenario

A hypothetical commuting trip was designed as illustrated in *Figure 4*. The origin of the trip is home, located in Weigongcun, and the destination is the workplace of the China World Trade Centre. The estimated travel distance of approximately 20 km. It is assumed that travellers will own and use a fully autonomous car for daily commuting in the future. The work duration is 8 hours per day and the parking fee is 60 Yuan per day at the workplace. Following this provided information on a user-friendly interface, the respondent is required to complete the subsequent stated choice questions regarding parking mode, parking location and shared use of autonomous vehicles.

Stated choice experiment on parking and shared use intentions

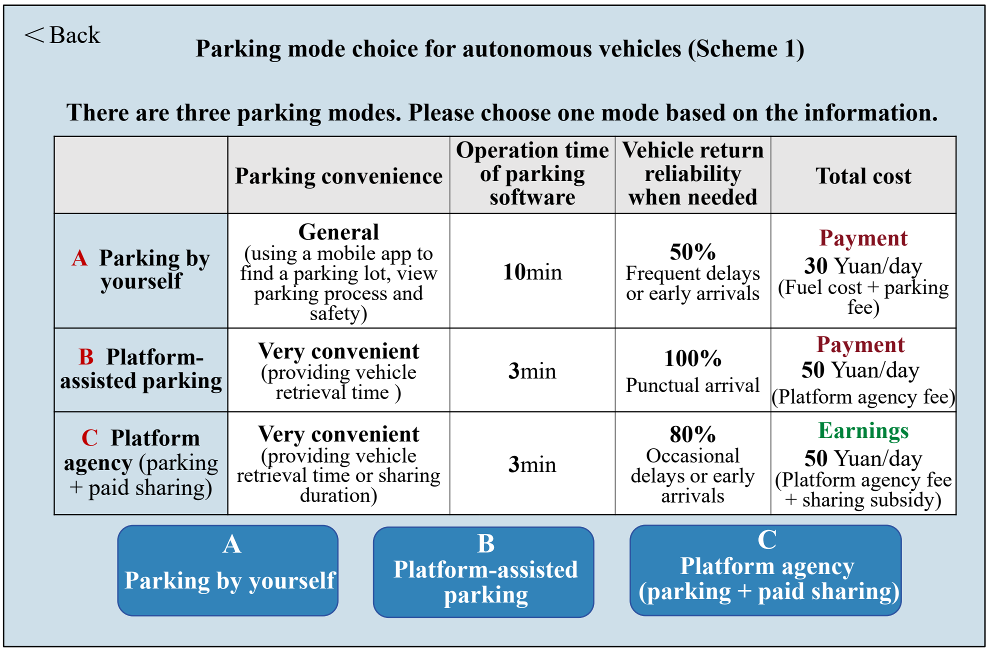
1) Design of parking mode choice for commuting with autonomous vehicles

It is assumed that parking and vehicle-sharing services for private autonomous vehicle use will be introduced in future transportation systems. Based on the hypothetical commuting scenario presented in *Figure 4*, three parking modes are available for travellers upon arrival. The first mode is “Parking by yourself”, which is somewhat like traditional parking, but slightly different. In this parking mode, users can utilize the smartphone parking app to search for a parking lot and subsequently allow their vehicle to automatically drive to the selected location. Travellers can also view the real-time positions of their vehicles during the autonomous driving process and observe whether the vehicle has safely entered a parking space. The second parking mode is “Platform-assisted parking”. Here, the control and use of the vehicle can be temporarily entrusted to the parking and sharing service platforms. The platform is responsible for selecting a parking lot and parking vehicles. Additionally, an agency fee, which includes a parking fee, is charged. The third parking mode is “Platform agency (parking + paid sharing)”. This mode involves temporary transfer of control and use of autonomous vehicles to the service platform. The platform can share vehicles with others when they are parked and not in use. Vehicle owners can earn sharing subsidies. The information described for the three parking modes is presented in a separate user interface to facilitate the travellers’ understanding.

Based on the three parking modes, four primary influencing factors were chosen to design the choice intention schemes. These include parking convenience, operation time for using parking software, reliability of vehicle retrieval when needed and travel costs or earnings related to the vehicle-sharing platform. Parking convenience refers to the time spent searching for a parking lot using a smartphone parking app, as well as paying attention to the parking process and safety when using the mode of “Parking by yourself”. When using a parking and sharing platform, convenience encompasses the operation time for assisted parking booking or the sharing process, such as the provision of information regarding vehicle retrieval times or sharing durations, via a smartphone app. The operation time for using parking software is closely related to the convenience of parking. The reliability of vehicle returns refers to the punctual degree of returning to the workplace when needed, taking into account the impact of unstable road traffic conditions.

Each factor was assigned to different levels. Four effective choice intention schemes are obtained through a combination of these factor levels. One or two of these schemes were randomly presented on an Intelligent Surface Tablet to each respondent in the survey. An example of a parking mode choice interface is shown in *Figure 5*.

Figure 4 – Hypothetical commuting scenario



	Parking convenience	Operation time of parking software	Vehicle return reliability when needed	Total cost
A Parking by yourself	**General** (using a mobile app to find a parking lot, view parking process and safety)	**10**min	**50%** Frequent delays or early arrivals	**Payment** **30** Yuan/day (Fuel cost + parking fee)
B Platform-assisted parking	**Very convenient** (providing vehicle retrieval time)	**3**min	**100%** Punctual arrival	**Payment** **50** Yuan/day (Platform agency fee)
C Platform agency (parking + paid sharing)	**Very convenient** (providing vehicle retrieval time or sharing duration)	**3**min	**80%** Occasional delays or early arrivals	**Earnings** **50** Yuan/day (Platform agency fee + sharing subsidy)

Figure 5 – An example of parking mode choice interface for autonomous vehicles

2) Design of parking location choice for commuting with autonomous vehicles

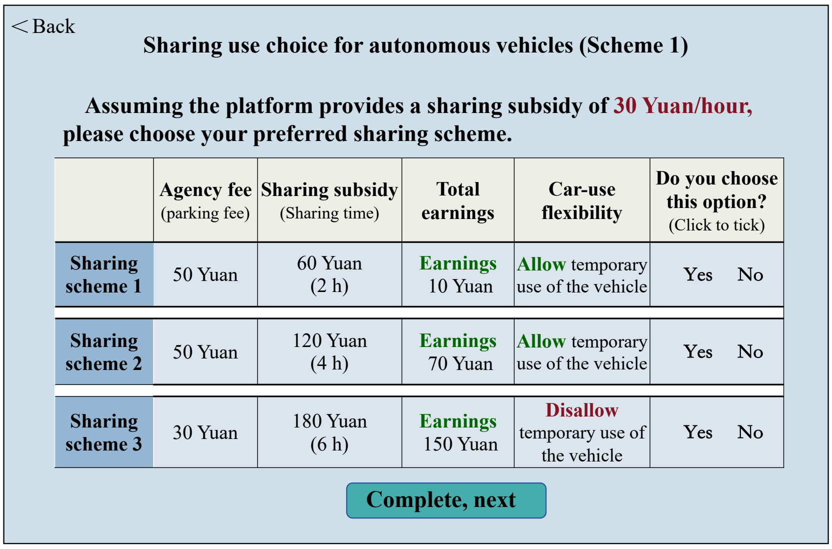
If a traveller selects "Parking by yourself" in the parking mode choice, they will directly proceed to answer questions about the specific parking location choice. At this time, the primary parking lots around the workplace are presented in the hypothetical commuting travel scenario to facilitate the travellers' views, as illustrated in *Figure 6*. For different parking locations, four primary factors were considered to affect the travellers' parking location choice: parking fees, automatic driving distance to the parking lot, round-trip driving costs, and reliability of vehicle return when needed. Parking fees, round-trip driving costs and reliability of vehicle return have six levels respectively. Automatic driving distance to the parking lot is set at three levels. Therefore, eight representative factor level combinations are obtained and divided into two groups. Each respondent answers one group of parking location choice questions randomly. A user interface for parking location choice is illustrated in *Figure 6*.

3) Design of shared use choice for commuting with autonomous vehicles

If a traveler chooses "Platform agency (parking + paid sharing)" as their parking mode, they will then be asked follow-up questions about sharing their privately owned autonomous vehicle while it remains idle during working hours. It is assumed that the vehicle-sharing platform provides two types of subsidies for the shared use of autonomous vehicles. Lower sharing subsidies have two levels: 10 Yuan/hour and 20 Yuan/hour. Higher sharing subsidies also have two levels: 30 Yuan/hour and 60 Yuan/hour. For each sharing subsidy, three factors are selected to describe the shared use choice schemes: platform agency fee, total earnings with different sharing durations and car-use flexibility. Car-use flexibility refers to whether a car can be retrieved and used temporarily, and it is categorized into two levels. The platform agency fee is set at three levels. Six representative intention combinations are selected for the lower and higher sharing subsidy conditions respectively and then divided into two groups, each with three car-shared use choice questions. Each participant randomly completed a group of car-shared use choice questions under higher and lower sharing subsidy conditions. An example of the interface design is shown in *Figure 7*.

		Parking fee	Distance from the workplace	Round-trip driving cost	Vehicle return reliability when needed	Do you choose to park here?
Remote parking lots	P1	30 Yuan/day	5 km	5 Yuan	95%	Yes No
	P2	15 Yuan/day	10 km	10 Yuan	70%	Yes No
	P3	free	15 km	20 Yuan	50%	Yes No
Parking near the workplace	P	60 Yuan/day	100 m	1 Yuan	100%	Yes No

Figure 6 – An example of parking location choice interface for autonomous vehicles



	Agency fee (parking fee)	Sharing subsidy (Sharing time)	Total earnings	Car-use flexibility	Do you choose this option? (Click to tick)
Sharing scheme 1	50 Yuan	60 Yuan (2 h)	Earnings 10 Yuan	Allow temporary use of the vehicle	Yes No
Sharing scheme 2	50 Yuan	120 Yuan (4 h)	Earnings 70 Yuan	Allow temporary use of the vehicle	Yes No
Sharing scheme 3	30 Yuan	180 Yuan (6 h)	Earnings 150 Yuan	Disallow temporary use of the vehicle	Yes No

Figure 7 – An example of shared use choice interface for autonomous vehicles

Survey on daily commuting behaviour and personal information

Before the travel experience for autonomous vehicles, respondents were asked about regarding their daily commuting behaviour and personal information. The items about daily commuting behaviours include departure time for commuting, one-way commuting time and cost, as well as comfort evaluation of commuting by public transport or car. The options for comfort evaluation range from "very uncomfortable (1)" to "very comfortable (5)" by using a 5-point Likert scale. For commuters who drive their cars, additional information regarding parking at their workplace is required. These encompass cruising time, parking fees and walking distance after parking. Ride-sharing experiences and the use of ride-hailing software are also explored, with three response options: "Never (1)" "Sometimes (2)" and "Often (3)".

Personal information includes gender, age, occupation, education level, personal monthly income, number of cars owned by household, whether the individual usually drives and whether they need to pick up and drop off children to and from school.

3.4 Survey implementation

In the Yizhuang autonomous driving service demonstration area, respondents were primarily recruited through online platforms such as Weibo and WeChat groups using random sampling. Random sampling can effectively ensure that the samples are representative, allowing them to better reflect the characteristics of the overall population. At the starting point of Route 1, they were asked to complete questionnaires covering their initial understanding and pre-experience perception of autonomous vehicles, daily commuting behaviours and personal information. Next, they reserved an autonomous driving service via a smartphone app and rode an autonomous vehicle along Route 1. Upon reaching the Route 1 destination, they experienced the autonomous vehicle's automatic parking process and completed a parking and shared use choice experiment using the Surface Tablet. They then rode the autonomous vehicle again along the return Route 2 back to the starting point, where they completed questionnaires regarding their post-experience perceptions and attitudes towards autonomous vehicles.

In the Shougang autonomous driving service demonstration area, respondents were primarily recruited on-site using convenience sampling. During the investigation period, many residents had experience with autonomous vehicles, which facilitated respondent recruitment and efficient data collection. At the start of Route 3, participants completed questionnaires covering their initial understanding and pre-experience perceptions of autonomous vehicles, daily commuting behaviours, and personal information at the start of Route 3. They then experienced an autonomous vehicle ride. Upon reaching the Route 3 destination, they completed the remaining survey questions.

Throughout the survey process, each participant was assigned a unique identifier to facilitate the matching of survey content across different locations. Each respondent took approximately one hour to complete the survey. A pilot survey was carried out to optimize the questions, questionnaire structure and sampling method. The formal survey was conducted from October 2021 to November 2022, with 303 participants completing all survey components. However, only 232 samples were considered valid, partly due to the complexity of the survey process. The expanded sample sizes for parking location choice and shared use choice are 244 and 426, respectively, which adequately meet requirements for regression analysis [31–33].

4. ANALYSIS OF THE SURVEY DATA REGARDING AUTONOMOUS VEHICLES BASED ON TRAVEL EXPERIENCE

4.1 Analysis of individual perception of autonomous vehicles

The travellers' initial understanding of autonomous vehicles is shown in *Figure 8*. The data reveal that 46% of respondents have only paid attention to relevant reports and information about autonomous vehicles through channels such as news and the internet before the travel experience. Additionally, 26% of the respondents had a fundamental understanding of the development and functionalities of autonomous vehicles. Overall, the respondents demonstrated a relatively low level of initial comprehension of autonomous vehicles.

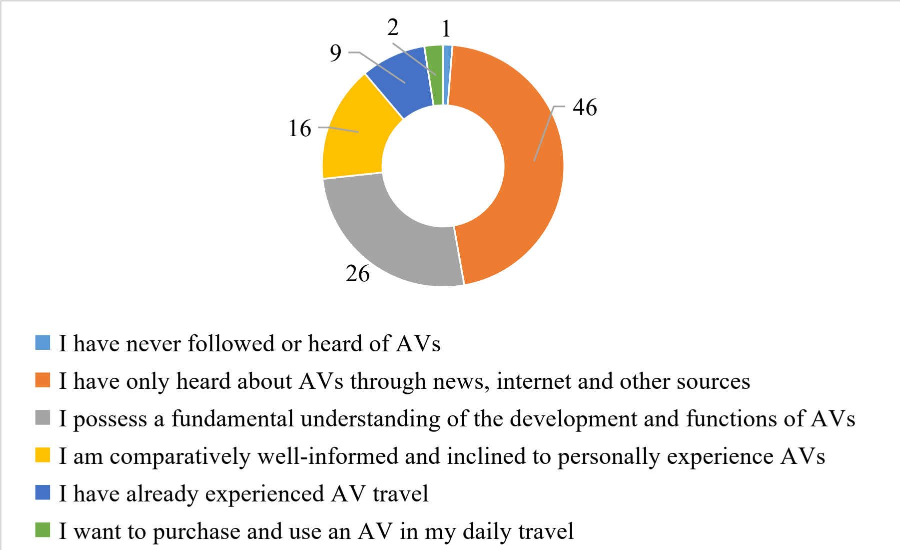


Figure 8 – Initial understanding of autonomous vehicles before the travel experience

A comparative analysis of the travellers' perceptions of autonomous vehicles is illustrated in *Figure 9*. After experiencing autonomous vehicles, the average perception scores for four aspects – travel process, daily use feelings, travel safety and impact on road traffic and the environment – were higher than before the experience. Notably, perceptions of daily use feelings and the travel process increased substantially, by 0.99 and 0.90 points, respectively. A paired t-test was conducted, showing that the two-tailed significance levels (Sig.) for all four perceived aspects were 0.000, indicating statistically significant changes. Additionally, these results suggest that the travel experience positively improved individuals' perceptions of autonomous driving.

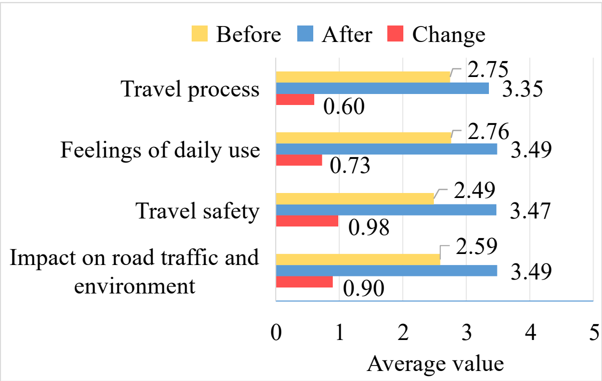


Figure 9 – Changes for four perceived aspects by the travel experience

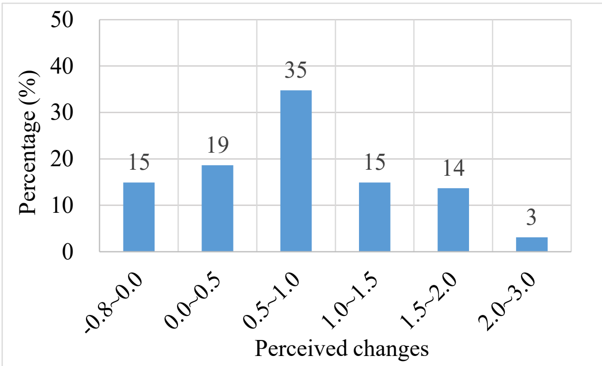


Figure 10 – Perceived changes distribution

To thoroughly evaluate changes in travellers' perceptions of autonomous vehicles, the concept of experience-perceived change was introduced. Based on the respondents' rankings of the travel process, daily use feelings, travel safety, and the impact on road traffic and the environment, the relative weight of attention given to each aspect can be calculated. Then the difference between respondent's weighted perception scores for these four aspects before and after the experience serves as a comprehensive indicator of experience-perceived change, as shown in *Figure 10.* The perceived changes mainly range from -0.8 to 3, with a mean of 0.83 and a standard deviation of 0.70.

4.2 Analysis of parking and shared use intentions for autonomous vehicles

As for the parking mode choice for commuting with private autonomous vehicles, *Table 1* shows that travellers who opt for "Parking by yourself" and "Platform agency (parking + paid sharing)" account for 41% and 39%, respectively. This suggests that, when a vehicle-sharing service is available, the majority of private autonomous vehicle users tend to favour compensated sharing schemes.

Table 1 – Parking and shared use intentions for autonomous vehicles

Parking modes	Percentage (%)	Parking location and shared use choice		Percentage (%)
Parking by yourself	41	Parking location choice	Parking near the workplace	42
			Parking at remote parking lot 1	82
			Parking at remote parking lot 2	52
			Parking at remote parking lot 3	19
Platform-assisted parking	20	–	–	–
Platform agency (parking + paid sharing)	39	Shared use choice	Shared use under lower sharing subsidy	50
			Shared use under higher sharing subsidy	67

For travellers who choose "Parking by yourself" while commuting with privately own autonomous vehicles, the proportions for subsequent parking location choices are as follows: near the workplace (42%), remote parking lot 1 (82%), remote parking lot 2 (52%), and remote parking lot 3 (19%). This indicates that travellers prefer remote parking lots 1 and 2, likely due to their lower parking costs and relatively higher reliability in terms of vehicle return when needed.

For travellers who choose the "Platform agency (parking + paid sharing)" mode, the subsequent shared use rate for autonomous vehicles are 50% under the lower sharing subsidy condition and 67% under the higher sharing subsidy condition. It can be inferred that a higher sharing subsidy may incentivise more individuals to opt for paid sharing of their own autonomous vehicles during idle periods.

4.3 Analysis of daily commuting behaviour characteristics

According to the survey data, *Table 2* demonstrates that 78% of commuters leave for work between 7:00 and 8:30 in the morning. Approximately 93% of commuters have a commute time of 60 minutes or less, and 72% experience a commute time of 40 minutes or less. Among commuters, 37% spend less than 5 Yuan commuting, while 43% spend between 5 and 20 Yuan. In terms of the comfort evaluation of their current commuting travel mode, 26% of commuters rate it as higher than "Generally comfortable", while 47% rate it as "Generally comfortable". 60% of commuters occasionally share rides with strangers, while 23% have never shared rides with others. Almost all commuters have used ride-hailing apps such as Didi and Gaode. Among them, 40% use them frequently, whereas 58% use them occasionally.

Table 2 – Characteristics of daily commuting behaviour

Items	Options	Percentage (%)	Items	Options	Percentage (%)
Departure time	Before 7:00	7	Comfortable level for current commuting mode	Very uncomfortable	6
	7:00~7:30	23		Uncomfortable	21
	7:30~8:00	31		Generally comfortable	47
	8:00~8:30	24		Comfortable	18
	After 8:30	15		Very comfortable	8
Commuting time	Less than 20 min	25	Ride-sharing experiences	Never	23
	20~40 min	47		Sometimes	60
	40~60 min	21		Often	17
	More than 1 hour	7	Ride-hailing apps use	Never	2
Commuting cost	Less than 5 Yuan	37		Sometimes	58
	5~10 Yuan	22		Often	40
	10~20 Yuan	21	Usually drives	Yes	58
	20~30 Yuan	12		No	42
	More than 30 Yuan	8			

Among private car commuters, 35% are able park their cars immediately near their workplace, while 59% spend between 1 and 10 minutes searching for a parking spot. This indicates that most commuters require some time to locate a parking space near their workplace. Among these private car users, most pay less than 5 Yuan per day for parking, however, 25% still incur daily parking fees exceeding 20 Yuan. After parking, 84% of commuters walk less than 200 meters to reach their destination.

4.4 Analysis of personal socio-economic information

The research target population for this study comprises commuters in Beijing aged 18 to 60 years. According to the survey data, *Table 3* shows that males account for a larger proportion of commuters (58%). The age of commuters is primarily between 18 and 40 years, comprising 84% of the sample. Most commuters work in enterprises and public institutions, or as professionals and technical personnel, accounting for 63%. Most respondents own one car in their household, accounting for 62%. The monthly income of commuters is primarily within the range of 5000–8000 Yuan, representing 36% of the sample. The education level of commuters is concentrated mainly in junior college and undergraduate degrees, with 30% and 42%, respectively. Notably, 83% of the respondents indicated that they do not need to take their children to and from school.

Table 3 – Statistics of personal socio-economic characteristics

Items	Options	Percentage (%)	Items	Options	Percentage (%)
Gender	Male	58	Monthly income	Less than 5000 Yuan	9
	Female	42		5000~8000 Yuan	36
Age	18~30 years old	47		8000~10000 Yuan	18
	31~40 years old	37		10000~15000 Yuan	19
	41~60 years old	16		More than 15000 Yuan	18
Occupation	Occupation 1: enterprises and public institutions personnel	30	Education level	High school or below	17
	Occupation 2: professionals and technical personnel	33		Junior college	30
	Occupation 3: self-employed and freelance; others	37		Bachelor	42
Number of cars owned by household	0	17		Master or above	11
	1	62	Need to take children to and from school	Yes	17
	No less than 2	21		No	83

According to the statistics from the Fifth Composite Transportation Survey in Beijing, published by the Beijing Municipal Commission of Transport in 2017, the gender distribution among the survey samples is largely consistent with the statistical data. The survey includes a higher proportion of young participants and high-income participants, potentially due to their greater interest in new technologies and a subsequent inclination to participate in the survey.

5. METHODOLOGY

Discrete choice models have been widely employed in the analysis of travel behaviour. The Multinomial Logit (MNL) model is commonly used. One limitation of the MNL model is its Independence of Irrelevant Alternatives (IIA), which tends to overestimate the choice probabilities of related alternatives and underestimate those of unrelated alternatives. The IIA assumption of the MNL model can be partially relaxed by considering the correlations among alternatives [34]. In this way, the derived Nested Logit model assumes that the choice set can be partitioned into several subsets, with error terms correlated among alternatives within each subset but uncorrelated across subsets. Therefore, this model can explain travel behaviours that violate the IIA assumption, making the behavioural analysis more realistic.

It is assumed that there are two decision layers: lower Level 1 and upper Level 2. The alternatives at Level 2 are represented as m and $m = 1, 2, \ldots, M_n$. M_n is the number of alternatives at Level 2. The alternatives at Level 1 are represented as r and $r = 1, 2, \ldots, R_{mn}$. R_{mn} is the number of alternatives at Level 1 based on the selection of m.

The Nested Logit model can be represented by the following equations.

$$P_n(rm) = P_n(r/m) \cdot P_n(m) \tag{1}$$

where $P_n(rm)$ represents the choice probability of alternative rm by traveller n, $P_n(r/m)$ denotes the choice probability of alternative r by traveller n given that alternative m has been chosen, and $P_n(m)$ represents the choice probability of alternative m by traveller n.

Based on the fundamental theory of disaggregate models, the choice probabilities for different decision levels can be expressed as follows:

$$P_n(r/m) = \frac{e^{\lambda_1 V_{(r/m)n}}}{\sum_{r'=1}^{R_{mn}} e^{\lambda_1 V_{(r'/m)n}}} \tag{2}$$

$$P_n(m) = \frac{e^{\lambda_2 (V_{mn} + V_{mn}^*)}}{\sum_{m'=1}^{M_n} e^{\lambda_2 (V_{m'n} + V_{m'n}^*)}} \tag{3}$$

$$V_{mn}^* = \frac{1}{\lambda_1} \ln \sum_{\mathrm{r}=1}^{R_{mn}} e^{\lambda_1 V_{(r/m)n}} \tag{4}$$

$$V_{rmn} = V_{(r/m)n} + V_{mn} + \varepsilon_{(r/m)n} + \varepsilon_{mn} \tag{5}$$

$$\lambda_1 = \frac{\pi}{\sqrt{6}\sigma_1} \tag{6}$$

$$\lambda_2 = \frac{\pi}{\sqrt{6}} \left(\sigma_2^2 + \frac{\pi^2}{6\sigma_1^2} \right) \tag{7}$$

$$V_{(r/m)n} = \sum_{k=1}^{K_1} \beta_k X_{(r/m)nk} \tag{8}$$

$$V_{mn} = \sum_{k=1}^{K_2} \theta_k X_{mnk} \tag{9}$$

where V_{rmn} denotes the total utility of alternative rm chosen by traveller n, $V_{(r/m)n}$ represents the deterministic component of the utility of choosing alternative r by traveller n given the choice of alternative m, V_{mn} is the deterministic component of the utility of choosing alternative m by traveller n that varies only with alternative m, and V_{mn}^* stands for the inclusive value, indicating how decision-makers' choices at level 2 are influenced by the total utility derived from the alternatives included at level 1. $\varepsilon_{(r/m)n}$ represents the random utility of alternative r for traveller n given the choice of alternative m, assumed to follow a Laplace distribution with a mean of 0 and a variance of σ_1^2. ε_{mn} is the random utility of alternative m for traveller n, assumed to follow a Laplace distribution with a mean of 0 and a variance of σ_2^2. $X_{(r/m)nk}$ denotes the k^{th} influencing factor of alternative r for traveller n given the choice of alternative m, β_k represents the estimation coefficient of $X_{(r/m)n}$, X_{mnk} stands for the k^{th} influencing factor included in alternative m for traveller n, and θ_k is the estimation coefficient of X_{mnk}. λ_1 and λ_2 signify the inclusion coefficient, where satisfaction of ($0<\lambda_1,\lambda_2<1$) indicates the rationality of the hierarchical structure of the Nested Logit model.

The Nested Logit model can be estimated using a staged approach. First, the lower-level model at Level 1 is estimated, and the corresponding inclusive values are calculated. These values are then incorporated into the upper-level model at level 2 for calibration.

6. MODELLING OF PARKING AND SHARED USE INTENTIONS FOR AUTONOMOUS VEHICLES

6.1 Structure of the decision-making model

For parking and shared use intentions regarding autonomous vehicles, two decision layers are established, as illustrated in *Figure 11*. Level 2 pertains to parking mode choice, which comprises three options: Parking by yourself (selecting a parking lot using a smartphone parking app and then allowing the vehicle to automatically drive to the selected location), Platform-assisted parking and Platform agency (parking + paid sharing). Based on Level 2, Level 1 includes two decision subsets. Among them, Level 1-1 focuses on parking location choice for autonomous vehicles and Level 1-2 concerns paid sharing use decisions during the idle periods of autonomous vehicles.

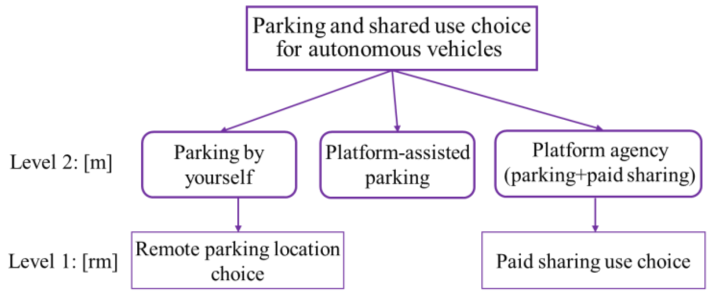


Figure 11 – The model structure for parking and shared use of autonomous vehicles

6.2 Modelling and analysis of parking and shared use of autonomous vehicles

Based on correlation analysis, the influencing factors for each decision level are initially selected. *Table 4* shows the assigned values for some influencing factors. In terms of car-use flexibility, a value of 1 is assigned if temporary vehicle pickup and use are allowed, and 0 is assigned otherwise. A value of 1 is assigned for 'Yes' and 0 for 'No' to indicate whether an individual frequently drives on weekdays. All other factors are regarded as continuous variables.

Table 4 – Assigned values for some influencing factors

Dummy variables					**Categorical variables**	
Variables	Classification	Assigned values			Variables	Assigned values
Occupation	Occupation 1: enterprises and public institutions personnel	1	0	0	Gender	Males: 1; Females: 0
	Occupation 2: professionals and technical personnel	0	1	0	Usually drives	Yes: 1; No: 0
	Occupation 3: self-employed and freelance; others	0	0	1	Needs to take children to and from school	Yes: 1; No: 0

The calibration results of the Nested Logit model are presented in *Tables 5* and *6*. It can be observed that the adjusted R-squared value of the parking mode choice model on Level 2 is 0.234 in the upper decision layer. Additionally, the adjusted R-squared values are 0.297 for the parking location choice model at Level 1-1 and 0.215 for the shared use model at Level 1-2. These values are within the acceptable range and indicate that the Nested Logit model demonstrates a relatively higher accuracy [35–36]. Furthermore, the inclusion coefficients λ_1 and λ_2 fall within the range of 0 to 1, indicating that the hierarchical structure of the Nested Logit model is appropriate and effectively captures the influence of various factors on travellers' decision-making regarding parking and the shared use of autonomous vehicles.

Table 5 – Calibration results of the parking mode choice model for autonomous vehicles (Level 2)

Decision layer	Choice	Variables	Coefficient	t-test
Level 2 (upper level)	Common variables	Operation time of using parking software	-0.073***	-5.12
		Reliability of vehicle return when needed	0.555**	2.27
		Travel cost related to parking or earnings from sharing platform	0.002***	4.25
	Parking by yourself	Constant 1	-0.803	-1.11
		One usually drives on weekdays	0.921***	6.23
		Gender	-0.285*	-1.77
		Age	-0.102***	-7.39
		Education level	-0.496**	-2.27
		Occupation 1: enterprises and public institutions personnel	-0.757**	-2.23
		Inclusion coefficient λ_1	0.754***	12.21
	Platform agency (parking + paid sharing)	Constant 2	-16.700***	-11.90
		Initial understanding of autonomous vehicles before the travel experience	0.256***	3.61
		Perceived change for autonomous vehicles due to the travel experience	0.539***	4.77
		Number of cars owned by household	-0.346***	-3.63
		Inclusion coefficient λ_2	0.341***	3.93
	Log likelihood value		598.2	
	Adjusted R-squared		0.248(0.234)	

*Note: ***, **, and * indicate significance at 99%, 95%, and 90% confidence levels, respectively.*

1) Analysis of the parking mode choice model for autonomous vehicles at Level 2

It is assumed that there are three parking modes available to commuters upon their arrival at the workplace. These include "Parking by yourself", "Platform-assisted parking" and "Platform agencies (parking + paid sharing)". Regarding the parking mode choice model at Level 2, the option of "Platform assisted parking" serves as a reference category and was thus not included in *Table 5*. The common variables refer to the influencing factors incorporated into the utility function for all available choice alternatives. The significant influencing factors include common variables of operation time of using parking software, reliability of vehicle return and travel cost or earnings. The coefficient for the operation time of using parking software is significantly negative, whereas the coefficients for the reliability of vehicle return and travel cost or earnings are significantly positive. This indicates that travellers are more inclined to choose a parking mode with more convenient software operation, higher vehicle return reliability and greater earnings when using autonomous vehicles for commuting. Therefore, by offering more user-friendly parking and sharing services through smartphone apps, along with higher sharing subsidies, the platform could attract more individuals to use it for parking or sharing autonomous vehicles.

For factors related to travellers' perceptions of autonomous vehicles, the coefficients initial understanding prior to experience and perceived change after experience are significantly positive. This suggests that individuals with favourable initial understanding of autonomous vehicles, and who perceive notable improvements in the travel experience – including daily usability, safety, and the impact on traffic and the environment – are more likely to choose the 'Platform agency (parking + paid sharing)' option, which enables vehicle sharing for compensation during working hours. Younger travellers, frequent drivers, women and individuals with lower education levels are more likely to prefer parking independently – using a parking app to locate a parking lot and allowing their vehicle to drive there autonomously.

Table 6 – Calibration results of parking and shared use models for autonomous vehicles (Level 1)

Decision layer	Choice	Variables	Coefficient	t-test
Level 1-1 (lower level)	Parking location choice	Constant 3	-7.525***	2.85
		Parking fees	-0.148***	-5.81
		Automatic driving distance * round-trip driving cost	-0.009**	-2.30
		Reliability of vehicle return	16.389***	3.88
		Perceived change for autonomous vehicles due to the travel experience	0.355**	2.48
		Evaluation of automatic parking on travel convenience	0.627**	2.32
		Cruising time for parking	0.186***	3.92
		Comfort evaluation of commuting by current travel mode	-0.139*	-1.83
		Monthly income	-0.000**	-2.11
		Education level	0.361*	1.91
		Occupation 3: self-employed and freelance; others	-1.255***	-3.54
	Log likelihood value		124.41	
	Adjusted R-squared		0.367(0.297)	
Level 1-2 (lower level)	Vehicle sharing use intention during idle periods	Constant 4	10.190***	5.07
		Platform agency fee	-0.067***	-4.01
		Vehicle sharing earnings	0.017***	4.35
		Car-use flexibility	2.058***	5.67
		Initial understanding of autonomous vehicles before the travel experience	0.301**	2.29
		Evaluation of the driving safety by using autonomous vehicles	1.260***	4.17
		Attitudes towards ownership of autonomous vehicles	0.486***	2.60
		Attitudes towards shared use of autonomous vehicles	0.353***	2.96
		Commuting time	0.346***	3.02
		Ride-hailing apps use	0.730***	2.92
		Need to take their children to and from school	-0.545**	-2.29
		Number of cars owned by household	0.452*	1.80
		Monthly income	-0.229**	-2.27
		Age	0.023	1.52
	Log likelihood value		158.78	
	Adjusted R-squared		0.267(0.215)	

*Note: ***, **, and * indicate significance at 99%, 95% and 90% confidence levels, respectively.*

2) Analysis of parking location choice for autonomous vehicles at Level 1-1

Regarding the parking location choice model at Level 1-1, the coefficient of parking fees is significantly negative and represents a considerable impact. This indicates that travellers are more inclined to choose remote parking lots with lower fees when using autonomous vehicles for commuting. The combined factor of automatic driving distance to the parking lot and round-trip driving cost has a significantly negative effect, suggesting that travellers prefer parking lots that are relatively closer to their destinations and have lower driving costs. Additionally, the significantly positive coefficient of vehicle return reliability indicates that travellers prefer parking locations where the vehicles have higher reliability in returning when needed, especially because of unstable road traffic conditions.

Regarding travellers' perceptions and attitudes towards autonomous vehicles, the change perceived after experience has a significant positive effect on the choice of parking location. This suggests that the greater the improvements travellers perceive in the travel process, daily usability, travel safety, and the impact on road traffic and the environment following their experience, the more willing they are to choose remote parking locations. Meanwhile, travellers who rate automatic parking highly for travel convenience are more likely to choose remote parking. Regarding factors related to travellers' daily commuting, those who spend more time searching for parking and perceive lower comfort using the current travel mode are more inclined to choose remote parking locations. Travellers with higher education levels, lower monthly incomes, and those employed by enterprises, institutions, or in professional roles are more willing to choose remote parking.

3) Analysis of the shared use of autonomous vehicles during idle periods at Level 1-2

Regarding the shared use intentions of autonomous vehicles at Level 1-2, the most significant influencing factors include platform agency fee, vehicle sharing earnings, and car-use flexibility. Travellers are more inclined to share autonomous vehicles with others when the sharing service platform provides relatively low agency fees and high sharing earnings with longer sharing durations. Meanwhile, travellers prefer the sharing option for autonomous vehicles which allows temporary vehicle access and retrieval.

As for factors related to travellers' perceptions and attitudes towards autonomous vehicles, those who have a favourable initial understanding of autonomous vehicles and a higher evaluation of their driving safety are more likely to share their autonomous vehicles with others. Travellers who view autonomous vehicles as mere transportation tools to facilitate travel and hold a more positive attitude towards paid shared use are also more inclined to opt for the shared use of autonomous vehicles. Therefore, increasing the public perception and sharing attitudes towards autonomous vehicles through travel experiences and advertising can encourage more people to accept car sharing.

Among the factors of daily commuting behaviour, travellers with longer commuting times and more frequent use of ride-hailing apps are more willing to choose the paid shared use of their autonomous vehicles. Conversely, those who frequently need to pick up or drop off their children are less inclined to share their autonomous vehicles. Travellers from households with more cars are more willing to choose to share their autonomous vehicles, whereas high-income groups are less inclined to opt for paid shared use.

6.3 Sensitivity analysis of parking and shared use model of autonomous vehicles

To conduct an in-depth analysis of the impact of important factors on parking and shared use decision-making behaviours related to autonomous vehicles, a sensitivity analysis was employed to assess the changes in travel choice resulting from these factors.

Sensitivity analysis of parking mode choice for autonomous vehicles

For the parking mode choice model at Level 2, four significant factors were selected to analyse their impact on parking mode choice behaviour. It is assumed that the operation time of using parking software varies from 1 to 25 minutes. The travel cost for parking or earnings from the sharing platform ranges from 80 Yuan/day in payments to 300 Yuan/day in earnings. The initial understanding of autonomous vehicles spans from 1 to 5. Pre- and post- experience perceived changes related to autonomous vehicles range from -2 to 4.

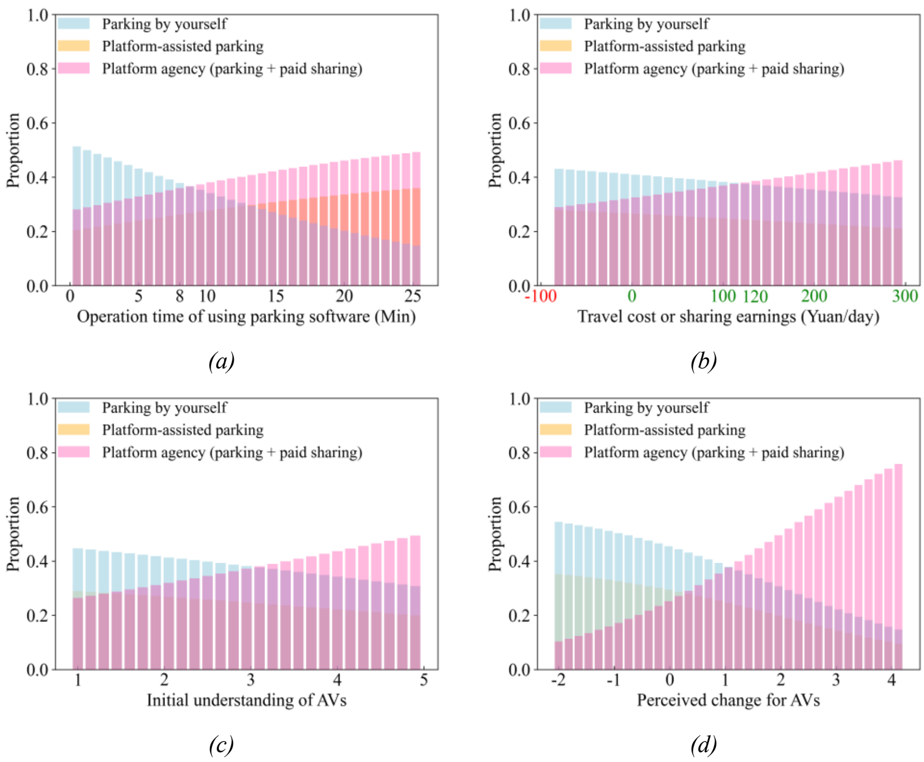
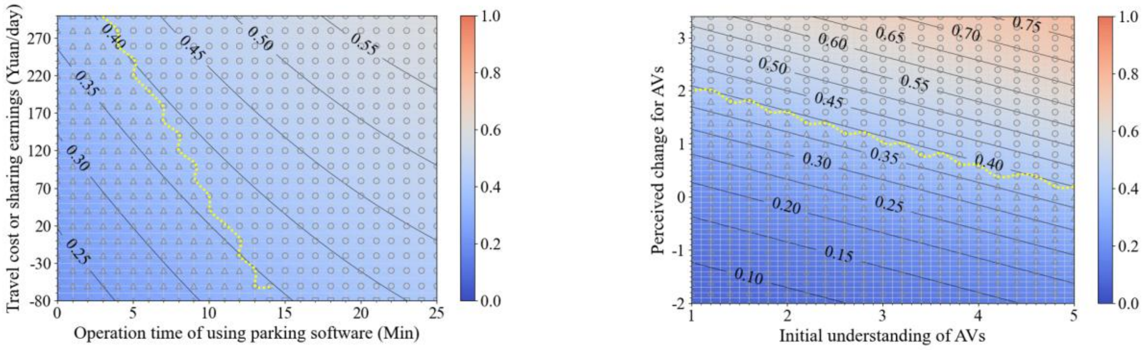


Figure 12 – Parking mode choice under different factors at Level 2: a) Operation time of using parking software; b) Travel cost or sharing earnings Yuan/day; c) Initial understanding of autonomous vehicles; d) Perceived change for autonomous vehicles

The impact of changes in a single factor on parking mode choice for commuting with autonomous vehicles is illustrated in *Figure 12*. When the operation time of using parking software reaches approximately 8 minutes, the parking mode choice starts to shift from 'Parking by yourself' to parking or paid sharing by the platform agency. Similarly, when the sharing earnings provided by the platform exceed approximately 120 Yuan/day, travellers are more inclined to choose 'Platform agency (parking + paid sharing)' instead of 'Parking by yourself'. Travellers who have a fundamental understanding of the development and functions of autonomous vehicles or a higher level of understanding are more willing to choose 'Platform agency (parking + paid sharing)'. If perceived changes brought about by the travel experience for the travel process, daily use feelings, travel safety, and the impact on road traffic and the environment exceed 1, it will prompt a shift in parking mode choice from 'Parking by yourself' and 'Platform-assisted parking' to 'Platform agency (parking + paid sharing)'.



(a) *(b)*

Figure 13 – Choice of 'Platform agency (parking + paid sharing)' with the changes of two factors: a) Operation time of parking software and travel cost or sharing earnings ; b) Initial understanding and perceived change for autonomous vehicles

Figure 13 illustrates the combined influence of the two factors on parking mode choice. When the two factors change within the area to the right of the yellow curves, travellers would select 'Platform agency (parking + paid sharing)'. As shown in *Figure 13a*, higher operation time of the parking software, especially those exceeding 15 minutes, can encourage more travellers to opt for 'Platform agency (parking + paid sharing)' regardless of the change of travel cost or sharing earnings by the platform. Relatively lower sharing earnings combined with inconvenient parking software use may entice travellers to choose 'Platform agency (parking + paid sharing)'. As shown in *Figure 13b*, when the perceive changes brought by the travel experience falls within the range of 0.5 to 2, a higher initial understanding of autonomous vehicles is required to attract travellers to use 'Platform agency (parking + paid sharing)'.

Sensitivity analysis of parking location choice for autonomous vehicles

For the parking location choice model at Level 1-1, four significant factors were selected to conduct the sensitivity analysis. It is assumed that the parking fee at different remote parking locations varies from 0 to 50 Yuan/day. The automatic driving distance to the parking lot, multiplied by round-trip driving cost, ranges from 0 to 300 km•Yuan. The reliability of vehicle returns due to unstable road traffic conditions varies from 0.5 to 1. Pre- and post-experience perceived changes for autonomous vehicles vary within the range of -3 to 4.

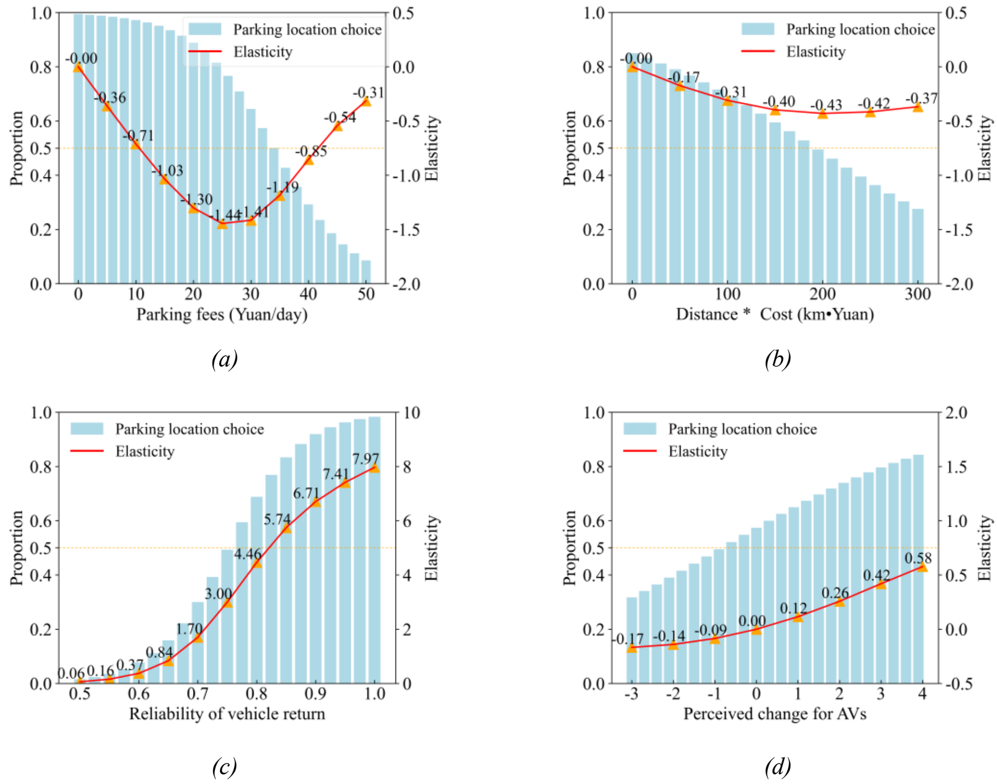


Figure 14 – Remote parking choice and elasticity values under different factors at Level 1-1: a) Parking fees; b) Driving distance round-trip driving cost; c) Reliability of vehicle return; d) Perceived change for autonomous vehicles*

As shown in *Figures 14a* and *14b,* for commuting trips with autonomous vehicles, the choice probability for remote parking decreases below 50% when the parking fee approaches approximately 35 Yuan/day. This means that travellers are less likely to choose a parking location with a parking fee exceeding 35 Yuan/day. Furthermore, when the parking fee at the remote parking lot varies from 15 to 35 Yuan/day, the elasticity values exceed 1, indicating that travellers are particularly sensitive to price changes within this range when choosing remote parking. Similarly, when the driving distance multiplied by the travel cost to the parking lot exceeds 200 km•Yuan, the number of travellers selecting that parking place decreases. Therefore, the acceptable remote parking locations for travellers are those with a parking fee of less than 35 Yuan/day and a driving distance of less than 20 km.

Figure 14c illustrates that parking locations with a vehicle return reliability exceeding 75% attract more people to park their private autonomous vehicles. When the reliability of the vehicle return reaches or surpasses 65%, the elasticity values exceed 1 and rapidly increase. Under these conditions, travellers are more sensitive to changes in the reliability of vehicle returns when making parking choices. *Figure 14d* indicates that travellers who have an equal or more positive perception of autonomous vehicles after their travel experience are more likely to choose the remote parking.

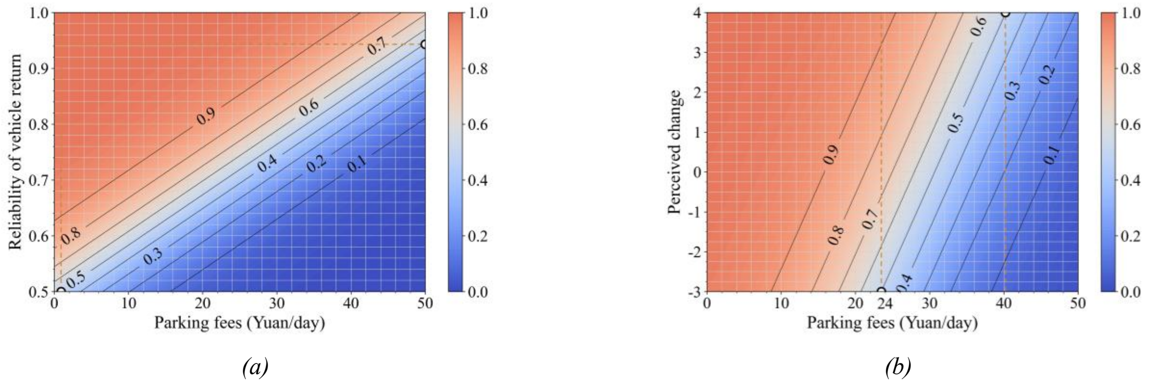


Figure 15 – Parking location choice with the changes of two different factors: a) Parking fees and reliability of vehicle return; b) Parking fees and perceived change for autonomous vehicles

Figure 15a illustrates the combined influence of parking fees and vehicle return reliability on the choice of remote parking locations. When the parking fees and reliability fall within the area to the left of the 50% contour line, travellers are more likely to select these locations for their autonomous vehicles. Offering free parking or vehicle return reliability near 100% encourages greater adoption of remote parking. However, imposing parking fees decreases the proportion of travellers choosing remote parking unless accompanied by a guarantee of higher return reliability.

Figure 15b shows that when the remote parking location has parking fees of less than 24 Yuan/day, almost all travellers prefer to park their private autonomous vehicles there, regardless of how their perception of autonomous vehicles changes owing to their travel experience. When the parking fees of the remote parking location increase from 30 to 40 Yuan/day, an improved perception of autonomous vehicles owing to travel experience can attract more travellers to park there.

Sensitivity analysis of shared use choice for autonomous vehicles

For the shared use choice model at Level 1-2, four factors have been selected to analyse the impact of their changes on the shared use of autonomous vehicles. It is assumed that the platform agency fee ranges from 0 to 80 Yuan and sharing subsidy earnings vary between 0 and 300 Yuan. The values of travellers' initial understanding and evaluation of driving safety for autonomous vehicles span from 1 to 5.

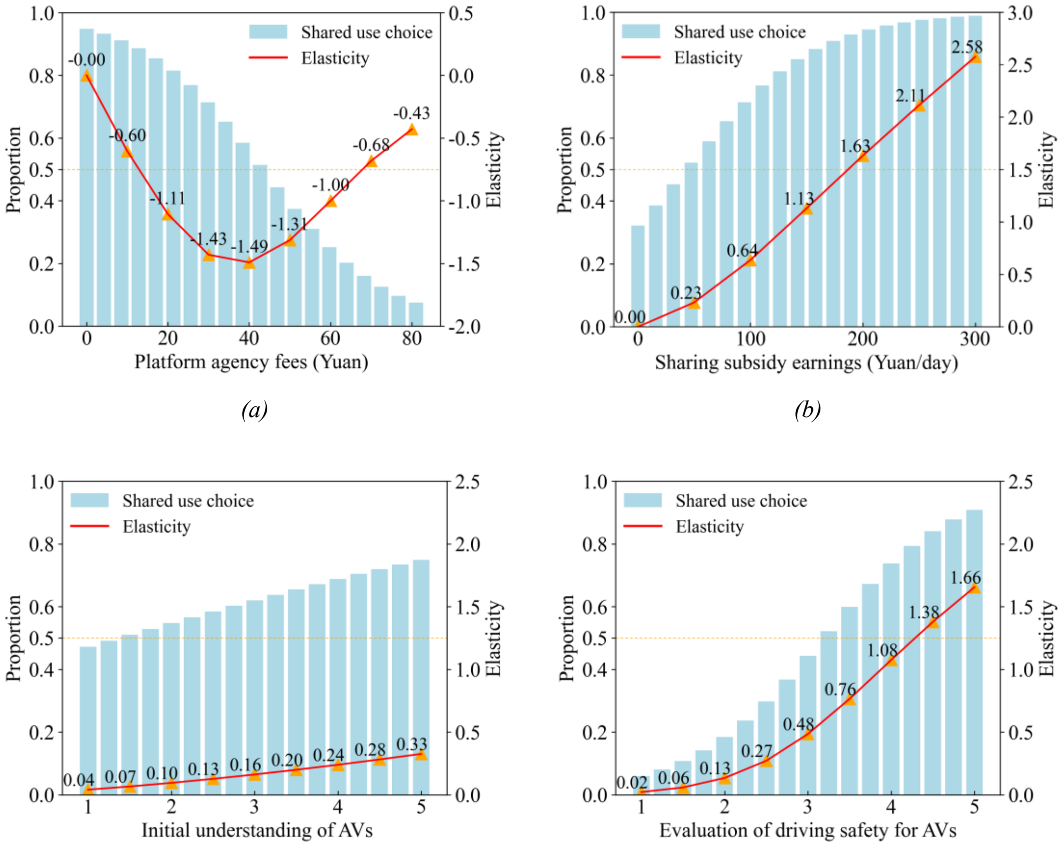


Figure 16 – Vehicle sharing choice and elasticity values under different factors at Level 1-2: a) Platform agency fees; b) Sharing subsidy earnings; c) Initial understanding of AVs; d) Evaluation of driving safety for AVs

As shown in *Figures 16a* and *16b*, the proportion of travellers choosing autonomous vehicles for shared use gradually decreases with as platform agency fees rise, but increases with higher sharing subsidy earnings. Specifically, when the platform agency fee surpasses 40 Yuan, the sharing choice proportion drops below 50%. This suggests that, to encourage vehicle sharing, the platform agency fee should be kept below 40 Yuan, while the sharing subsidy earnings should exceed 50 Yuan/day. Furthermore, travellers are more sensitive to changes in the range of 20 to 60 Yuan for the platform agency fee, with elasticity values exceeding 1. Similarly, if the sharing subsidy earnings surpass 150 Yuan/day, this will have a significant impact on the choice to share vehicles. These sensitive ranges can serve as the foundation for traffic policy regulation in the upcoming era of autonomous driving.

As demonstrated in *Figures 16c* and *16d,* low initial understanding of autonomous vehicles can also encourage more travellers to share their private autonomous vehicles during idle periods. When the evaluation of driving safety for autonomous vehicles reaches the level of 'as safe as or safer than traditional cars', more travellers will opt to share their private autonomous vehicle for compensation. Travellers are more sensitive to changes in the evaluation of autonomous vehicle driving safety when it is rated as 'safer or much safer than traditional cars'.

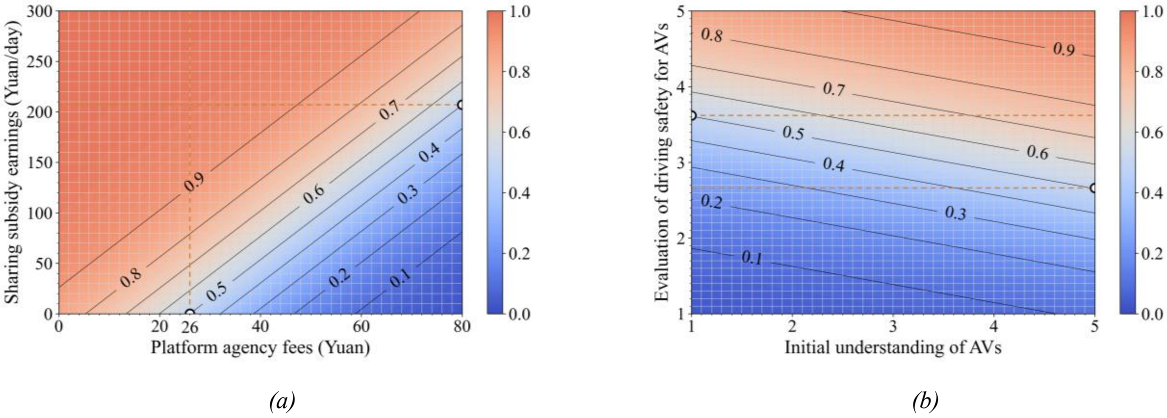


Figure 17 – Vehicle sharing choice with the changes of two different factors: a) Platform agency fees and sharing subsidies earnings; b) Initial understanding of AVs and evaluation of driving safety for Avs

As shown in *Figure 17*, when platform agency fees are less than 26 Yuan or sharing subsidies earnings exceed 200 Yuan, almost all travellers prefer to share their private autonomous vehicles. Meanwhile, high platform agency fees, particularly those exceeding 26 Yuan, must be accompanied by higher sharing earnings to incentivise travellers to opt for the shared use of their autonomous vehicles.

Similarly, when the evaluation of driving safety for autonomous vehicles approximates or exceeds the level that is 'safer than traditional cars', most travellers prefer to share their private autonomous vehicles, regardless of how their initial understanding of autonomous vehicles may vary. Conversely, a relatively lower evaluation of driving safety, combined with a higher initial understanding of autonomous vehicles, can still encourage travellers to choose the shared use of their autonomous vehicles.

6.4 Results and discussion

This study investigates parking and shared use behaviours of privately owned autonomous vehicles. In terms of parking mode choice, our findings reveal that commuters prefer parking modes offering more convenient software interfaces, higher vehicle return reliability and greater earnings. Individuals with good understanding and enhanced perception of autonomous vehicles through experience demonstrate greater preference for 'platform agency (parking + paid sharing)'. Furthermore, young travellers, frequent drivers, female commuters, and those with lower educational levels are more inclined to park their vehicles by themselves. These behavioural patterns and relationships represent new insights to travel research, as prior studies have not systematically state these contents.

Our analysis of parking location preferences reveals that travellers predominantly favour remote parking facilities offering lower parking fees, closer proximity to destinations and lower driving costs. These findings align with prior research [5–6, 19–20], demonstrating the significance of parking costs and parking-related distances on parking decisions. Additionally, our findings indicate that vehicle return reliability and perceptual factors related to autonomous vehicles also play important roles in the choice of remote parking locations. Specifically, travellers who develop improved perception after the travel experience and rate highly the convenience of automatic parking are more likely to choose remote parking lots. This contrasts with Millard-Ball's observations of persistent destination-proximal parking preferences for travel with autonomous vehicles [23].

Our analysis of private vehicle-sharing behaviours demonstrates three key platform-related factors that significantly influence shared use adoption: lower agency fees, higher sharing earnings, and flexible vehicle access and retrieval. In addition, travellers who often need to pick up and drop off children show lower sharing propensity. These findings provide new insights into the influence of platform- and family-related factors on vehicle-sharing decisions. Notably, we found that high-income groups show reduced willingness to share their private autonomous vehicles through sharing platforms, contrasting with Dias et al.'s established correlation between income and conventional car-sharing service adoption [24]. Furthermore, while existing literature emphasizes perceived risk and usefulness as primary adoption determinants [9, 28], our results highlight the significance of initial understanding of autonomous vehicles and positive attitudes toward paid sharing in facilitating shared use of privately owned autonomous vehicles.

7. CONCLUSION

With the rapid development of new technology, autonomous driving has become a promising travel mode in daily life. Autonomous vehicles are capable of automatically driving and parking. This creates convenient conditions for owners to share their autonomous vehicles for compensation when the vehicles are not in use. These features bring significant implications for the layout of the parking infrastructure and car-sharing practices. This study conducted a survey on parking and shared use intentions of autonomous vehicles based on a travel experience in the field with a virtual cruising and parking system. By taking travellers' perceptions and attitudes into account, their choice behaviour regarding parking modes, parking locations and the shared use of autonomous vehicles was thoroughly analysed. Additionally, a sensitivity analysis was performed to examine the impact of critical factors on parking and shared use preferences. The main findings and conclusions are as follows.

The analysis of the survey data reveals that travellers have a relatively low level of initial comprehension of autonomous vehicles. However, travel and parking experiences have enhanced individual perceptions of autonomous vehicles, particularly regarding daily use feelings and travel process. If a parking and sharing platform for private autonomous vehicles is available, most travellers tend to opt for schemes that involve compensated sharing.

A behavioural model was established using Nested Logit models to explore travellers' parking and shared use intentions regarding private autonomous vehicles. The upper decision layer pertains to parking mode choice, whereas the lower layer focuses on remote parking and sharing use choice. The model results indicate that travellers are more inclined to choose a parking mode that offers more convenient software operation, higher vehicle return reliability and greater earnings. Individuals who have a favourable initial understanding of autonomous vehicles and a significantly improved perception after the travel experience are more likely to choose 'Platform agency (parking + paid sharing)' instead of 'Parking by yourself'.

Regarding the use of autonomous vehicles for commuting, travellers tend to prefer remote parking locations that offer lower parking fees, closer proximity to the destination, lower driving costs, and higher vehicle return reliability. The acceptable remote parking locations are those with a parking fee of less than 35 Yuan, a driving distance of less than 20 km and a reliability of vehicle return exceeding 75%. Travellers are particularly sensitive to changes in parking fees within the range of 15 to 35 Yuan/day for parking location choice. Travellers who perceive autonomous vehicles equally or more positively after the travel experience, compared to before, are more likely to prefer remote parking.

If the vehicle-sharing service platform offers lower agency fees, higher sharing earnings and allows for temporary vehicle access and retrieval, travellers are more likely to choose to share their own autonomous vehicles during idle parking periods. Those who have a favourable initial understanding of autonomous vehicles and hold a more positive attitude towards car sharing are more inclined to opt for the shared use of autonomous vehicles. To promote vehicle sharing, an appropriate platform agency fee should be set at less than 40 Yuan and sharing subsidy earnings should exceed 50 Yuan/day. The sensitive ranges for travellers' decisions on car sharing are between 20 and 60 Yuan for platform agency fees and exceeding 150 Yuan for sharing subsidy earnings. Therefore, increasing shared subsidies by the service platform and enhancing the public's sharing attitude and perception of autonomous vehicles through travel experiences and advertising can encourage more people to accept sharing their autonomous vehicles with others. The improved use of vehicle sharing reduces parking demand and increases the utilization of private autonomous vehicles.

These research conclusions can provide a reference for theoretical exploration and practical implications for private autonomous vehicle-sharing travel in future transportation systems. Theoretically, they can advance the understanding of parking and shared use behavioural characteristics and identify critical determinants influencing the market penetration of private vehicle-sharing services. In terms of practice, these findings provide valuable insights for developing parking policies adapted to the autonomous vehicles era. For example, implementing region-based differentiated parking fees or tiered parking pricing scheme could effectively incentivise commuters to choose shared use of their own autonomous vehicles. Additionally, offering targeted subsidies or preferential policies to autonomous vehicle owners who share their idle vehicles could encourage broader adoption of this emerging shared mobility model. Furthermore, establishing well-defined regulatory frameworks for vehicle-sharing platforms would ensure fair competition and operational transparency, fostering sustainable systems for shared mobility. Such integrated policy approaches will facilitate the application and optimization of autonomous vehicle-sharing services in the future.

This study represents a preliminary exploration in the field of parking and shared use of autonomous vehicles. Given the limited samples in Beijing, future research will expand the scope of the investigation to include more cities like Wuhan, Shanghai and Shenzhen to address geographical coverage and cover diverse demographic groups. This expansion enables more thorough and reliable analysis of parking and shared use behaviour when it comes to autonomous vehicles. Furthermore, individual heterogeneity can be modelled through a random parameters nested logit framework, which allows variations in parameters across respondents. Additionally, different service modes for the vehicle-sharing platform can be incorporated into research on the shared use of autonomous vehicles, and their effects can be further examined.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

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