Analysis of Cruising Process and Psychological Decision of On-Street Parking

Huanmei QIN[1], Qianqian PANG[2], Meina CHENG[3], Yan HAN[4]

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[1] hmqin@bjut.edu.cn, Beijing Key Lab of Traffic Engineering, Beijing University of Technology, Beijing, China
[2] 2445045337@qq.com, Laboratory of Urban ITS, School of Transportation, Southeast University, Nanjing, China
[3] 1816199420@qq.com, Beijing Key Lab of Traffic Engineering, Beijing University of Technology, Beijing, China
[4] Corresponding author, 56723723@qq.com, Beijing Key Lab of Traffic Engineering, Beijing University of Technology, Beijing, China

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ABSTRACT

Due to the imbalance between parking supply and demand, cruising for parking frequently brings substantial impacts on road traffic. A concurrent video and questionnaire on on-street parking was conducted in Beijing to address these issues. From a procedural and psychological perspective, a structural equation model was established to examine the relationship between psychological factors and the characteristics of the cruising process. It was concluded that travellers display different cruising characteristics for parking under different conditions. In relatively unsaturated on-street parking occupancy conditions, travellers demonstrate greater variability in their vehicle trajectories and hesitate when making parking decisions. Conversely, in saturated conditions, they exhibit small fluctuations and fear the unavailability of parking spaces ahead. Short-term parkers typically prefer parking as close as possible to their destination and may opt to park illegally if these are full. Psychological and parking-related features play a crucial role in directly shaping on-street cruising characteristics. Additionally, individual differences, parking features and the occupancy status of parking spaces can exert indirect influences on this process through the mediation of psychological factors. Targeted policies can be developed based on different cruising psychology analyses to influence travellers' parking decisions and mitigate the negative impacts of cruising for parking on road traffic.

KEYWORDS

vehicle trajectory; cruising and parking process; cruising psychology; structural equation model.

1. INTRODUCTION

Owing to the rapid increase in the number of motor vehicles and the low supply of parking spaces, parking problems are becoming increasingly severe. Among them, cruising for parking not only prolongs travellers' travel time and reduces traffic efficiency but also exacerbates traffic congestion and emissions [1-2]. The vehicles cruising for parking often drive at low speeds and in a stop-and-go state. The research conducted by Shoup (2006) indicates that the time spent searching for on-street parking spaces in urban centres can vary from approximately 3.5 to 14 minutes. Furthermore, 8% to 74% of traffic in the transportation system is dedicated to the search for parking spaces [3]. To mitigate the negative effect, some methods such as parking demand management are effective for addressing parking issues, while the analysis of travel behaviour can provide a solid foundation for policy formulation in demand management [4]. According to recent studies, it is found that travellers' cruising behaviour for parking is influenced by various factors, such as parking occupancy, walking distance after parking and their socio-economic information [5]. However, few studies have focused on the effects of microscopic psychological factors on the macroscopic cruising process and parking behaviour. Consequently, it is imperative to investigate the impact of these factors to better understand the diverse characteristics exhibited during the cruising process for parking.

As an essential component of urban parking systems, on-street parking offers greater convenience and is primarily utilised by short-term parkers. During the on-street cruising and parking process, interferences between motorised and non-motorised vehicles often have adverse impacts on road traffic. Meanwhile, psychological factors also demonstrate a significant impact on parking behaviour. To address these issues, this study primarily focuses on car travellers' cruising and parking behaviour from both a process and psychological perspective. Based on a video survey and an accompanying parking behaviour survey conducted at Youshige Business MALL in Beijing, we conducted an in-depth analysis of car travellers' cruising trajectories and extracted their behavioural characteristics during the cruising and parking processes. Furthermore, we explored the effects of personal information, psychological factors and parking-related factors on cruising for parking. The research conclusions can offer valuable insights for improving parking efficiency and alleviating parking problems.

2. LITERATURE REVIEW

In recent years, some studies have been conducted on cruising behaviour for parking and its influencing factors. Shoup [3] delved into the phenomenon of cruising for both on-street and off-street parking choices, concluding that when the cost of curb parking is equivalent to or exceeds that of nearby off-street parking, cruising for parking can be significantly reduced. Khaliq et al. [6] employed a mixed multinomial logit model to investigate the decision-making process behind on-street parking choices, finding that parking fees, payment methods and anticipated parking durations significantly impact travellers' parking location preferences. Mei et al. [7] formulated a choice utility function incorporating travel time, cruising time and parking price, then utilised a probit-based model to determine that travellers' attitudes and perceived factors play a crucial role in their parking choices. Soto et al. [8] utilised a hybrid discrete choice model to examine the effects of observable factors and individual-specific latent attributes on parking choice. Their findings revealed that risk aversion and a positive attitude towards car care are significant determinants of parking choice. Liang et al. [9] applied the technology acceptance model and the theory of planned behaviour to understand travellers' intentions towards using shared parking. Their study identified perceived control and self-efficacy as the most influential factors affecting the choice of shared parking. Li et al. [10] employed a discrete choice model to explore the parking choice behaviour of urban village residents, discovering that parking fees, search time and walking distance to home negatively impact parking decisions. Ye et al. [11] constructed a multinomial logit model to analyse the relationship between travellers' parking choices and influential factors. The results showed that parking cost, excursion cost and parking time are the primary determinants of travellers' parking behaviour.

Cruising for on-street parking can negatively impact road traffic, and there are some methods available to mitigate this issue [12]. Hampshire et al. [13] used video data to study the cruising behaviour of car travellers, including cruising start time, cruising distance and cruising time for parking. Their findings revealed that 70% of cruising metres were generated by 30% of drivers. These conclusions can also aid in estimating the number of vehicles engaged in cruising for parking and the resulting pollution. Liu and Geroliminis [14] simulated cruising behaviour for parking using a dynamic aggregated traffic model. They found that cruising for parking increases travel distance, decreases network outflow and contributes to traffic congestion. Ommeren et al. [15-16] used a random sample of car trips to investigate cruising behaviour for parking. Their research indicated that cruising time increases with travel time and parking time. It was suggested that adjustments to parking prices or providing information about available parking spaces could effectively reduce cruising time. Arnott et al. [17] developed a parking choice model specifically for an urban central area. Their analysis revealed that increasing the on-street parking price is an effective strategy for reducing cruising for parking in situations where on-street parking is saturated. Amer and Chow [18] introduced an on-street parking model for an urban central area to analyse the parking demand of freight cars. Their research indicated that both raising parking fees and implementing pre-allocated parking spaces can effectively diminish the need for vehicles to cruise in search of parking. Moradkhany et al. [19] introduced an optimisation algorithm tailored to analysing commuters' cruising for parking on university campuses. Utilising the University of Akron as a case study, they demonstrated the algorithm's ability to adjust parking demand and successfully reduce cruising time by 20%.

The research discussed primarily used the discrete choice model and theory of planned behaviour to analyse cruising behaviour for parking and its influencing factors such as parking fees, parking durations and walking distance. They also used a simulated method and optimisation algorithm to estimate the negative effect arising from cruising for parking and explore strategies such as adjustments to parking prices or providing information to mitigate it. When approaching trip destinations, the cruising and parking process for travellers can be intricate, involving numerous decisions and behavioural adjustments. This process is influenced by various factors such as road traffic, availability of parking space and parking fees. To analyse this process, vehicle trajectory data can be used to investigate travellers' dynamic cruising and parking behaviours. However, this area has received limited attention. Existing studies predominantly utilise vehicle trajectory data to analyse travel characteristics and demand patterns. For instance, Wang et al. [20] delved into the spatio-temporal characteristics of trips and their influencing factors, leveraging trajectory data from taxis and ride-sharing cars. They further capitalised on these travel patterns to suggest pricing strategies. Similarly, Ghosh et al. [21] employed large-scale taxi trip data to construct a mobility dynamic network capable of anticipating travel demands. An end-to-end mobility association rule mining framework, named MARIO, has been successfully deployed on the Google Cloud Platform, showcasing its effectiveness.

In this research, we delve into travellers' cruising and parking behaviour from both process and psychological perspectives. The primary contributions of this study are as follows:

1) A comprehensive on-street parking survey, incorporating both video capture and parking behaviour inquiries, was designed and conducted concurrently. This approach enabled us to gather data on cruising trajectories, parking behaviours, as well as the psychological aspects of cruising behaviours.
2) Fluctuation values for vehicle trajectory and driving speed were proposed to characterise the variability during cruising and parking processes. Given different on-street parking occupancy situations and traffic interference, vehicle trajectories were classified to analyse cruising characteristics and psychological states associated with parking behaviour.
3) A structural equation model was employed to delve deeply into the direct and indirect relationships between personal information, parking-related factors, psychological factors and cruising behaviour for parking. It has been determined that cruising psychology has a mediating effect on on-street cruising behaviour for parking. The research findings can illuminate behavioural patterns related to cruising for on-street parking and offer valuable insights for the development of parking policies.

3. CRUISING PROCESS AND ON-STREET PARKING SURVEY

To explore the characteristics of the cruising process, an on-street parking survey was designed. The vehicle trajectories were classified and analysed, taking into consideration the questionnaire data that focused on parking behaviours and their psychological features.

3.1 Survey summary

To gather data on travellers' cruising process and parking behaviour, a well-established commercial complex, Youshige Business Mall, located in Beijing, was selected as the survey site. The mall is situated close to Guangqumenwai Avenue, as illustrated in *Figure 1*, and attracts a significant number of visitors, thereby generating substantial parking demand. Adjacent to Youshige, approximately 34 parking spaces are available on the relief road. During daytime hours (7:00-21:00), the parking fee is set at 2.5 Yuan (0.32 EUR) per 15 minutes for the first hour, with an increase to 3.75 Yuan (0.48 EUR) per 15 minutes thereafter. This section of the road comprises one motorised lane and one non-motorised lane, with no divider separating them, potentially leading to interference between motorised and non-motorised vehicles.

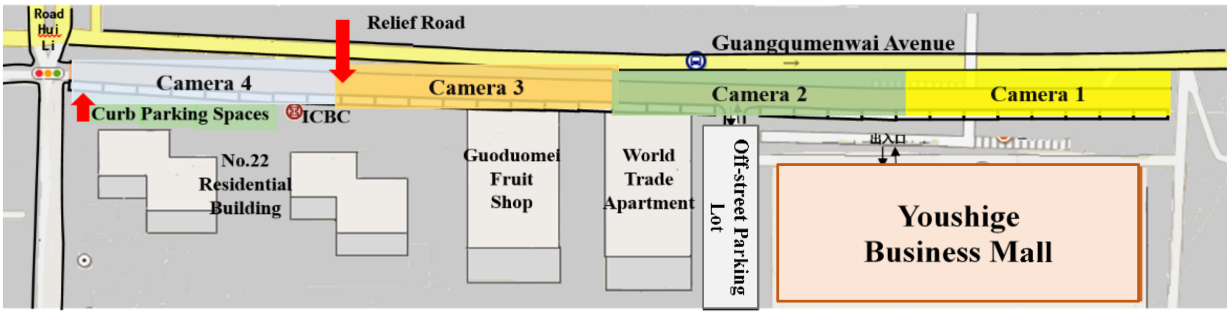


Figure 1 – Survey site

A video survey was conducted to capture vehicle trajectories during the cruising process for parking. To ensure comprehensive coverage, four cameras were strategically positioned along the relief road, with each camera monitoring approximately 8–9 parking spaces. These cameras recorded travellers' cruising processes, parking positions, occupancy levels of on-street parking spaces and instances of vehicle interference. The survey was carried out on three separate occasions between June 2017 and May 2018, with each session lasting 120 minutes during the evening rush hour periods on weekends.

In conjunction with the video survey, a questionnaire survey was conducted simultaneously to gather insights into travellers' cruising and parking behaviours and their psychological features. The questionnaire was structured into three parts, as illustrated in *Table 1*.

Table 1 – The contents of the questionnaire

Contents	Detailed description
Personal information	- gender, age, occupation and monthly household income
Travel and parking behaviour	- parking time, familiarity with the area, the number of occupants in the car, walking distance after parking and other pertinent factors
Psychological features of travellers during the cruising and parking process	- expectations of finding empty parking spaces near their destination - psychological states experienced during the cruising process - psychological state of choosing the current parked position - degree of regret upon finding an empty parking space near the destination after parking

The questions pertaining to the psychological features of travellers during the cruising and parking process are as follows:

1) The questions pertaining to travellers' expectations of finding empty parking spaces near their destination during the cruising process include options such as "There must be empty parking places", "There may be empty parking places" and "There may not be any parking places".
2) The psychological states experienced during the cruising process encompass the following options: "Worry about no empty parking space ahead and park far from the destination upon spotting an available space", "Depending on the situation, park immediately upon finding a space if more cars are parked along the road or continuing to drive if fewer cars are present", "Relying on past parking experiences" and "Others".
3) The questions addressing the psychological state of choosing the current parked position comprise the following options: "Take a chance", "Believing there must be empty parking spaces here", "Basing decisions on previous parking experiences" and "Others".
4) The degree of regret upon finding an empty parking space near the destination after parking includes options of "No regret at all", "A little bit of regret" and "Very regretful".
5) The parking choices available to a traveller when they arrive at their destination only to find no empty parking spaces include options of "Circle back and cruise again", "Continue to search for parking spaces ahead", "Change his/her destination" and "Park anywhere with an open space".

The survey was conducted through face-to-face interviews. Participants were selected from travellers who parked their cars on the specified road section. Concurrently, the licence plate information of the respondents was recorded to facilitate subsequent matching with vehicle trajectories in the video data. Due to the difficulty in interrupting the flow of moving vehicles, travellers who did not find parking spaces upon arriving at the mall and continued to cruise were not collected in this research. Ultimately, 136 valid questionnaires were successfully obtained.

3.2 Trajectory extraction and analysis of questionnaire data

Based on the collected video data, George software was utilised to extract the trajectories of moving vehicles destined for Youshige. Upon importing a video into the software, the coordinates of six reference points were carefully selected and inputted to establish a plane coordinate system. For each frame, as illustrated in *Figure 2*, a specific position of the same vehicle, such as the licence plate, can be clicked to add a point to the trajectory. With an interframe space of 0.1 seconds, once the clicking process was completed, the software automatically smoothed all trajectory points and generated a vehicle trajectory, as depicted in *Figure 3*. Additionally, the software can output a table containing the horizontal and vertical coordinates, speed, time and acceleration of all the trajectory points. By leveraging the car-plate information, the complete cruising trajectory for a car traveller was obtained by sequentially merging the segmented trajectories of the same vehicle extracted from the four cameras. Valuable information such as the occupancy statuses of on-street parking spaces, vehicle interference and traffic conditions along the relief road was collected.

Figure 2 – A frame image and trajectory points

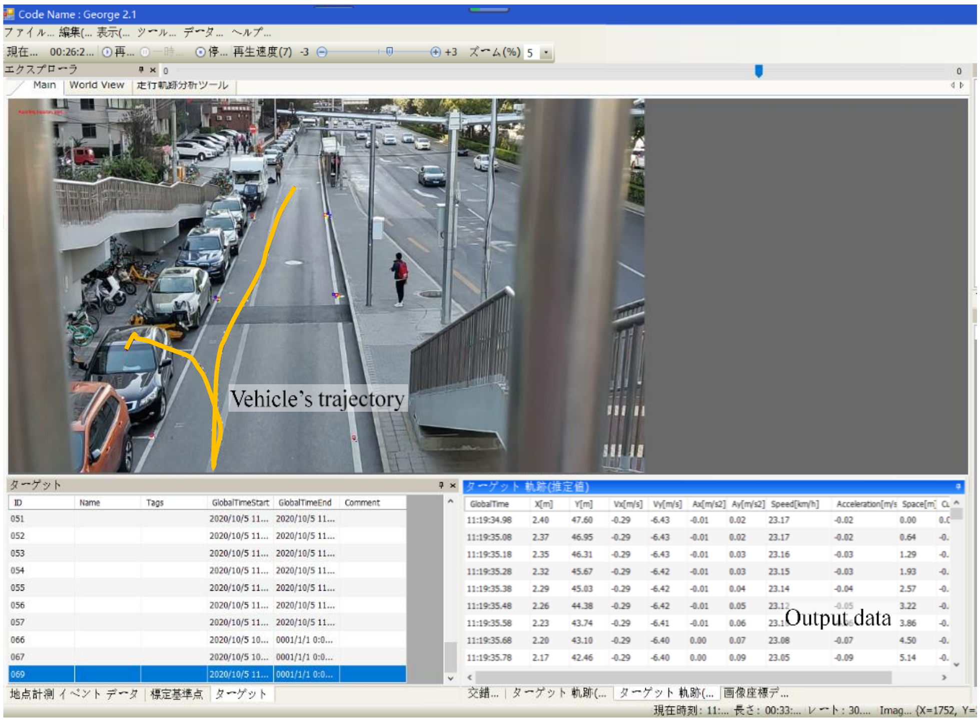


Figure 3 – Vehicle's trajectory and output data

Taking into account the effects of shelters and other potential interferences on licence plate recognition, a total of 243 vehicle samples were ultimately acquired. Out of these samples, 46 vehicles were observed to pass through the relief road directly, while 197 vehicles were found to be parked.

Based on the questionnaire data, 68% of the respondents are male. The majority of respondents fall within the age range of 26–45 years old, comprising 71% of the total. The distribution of the respondents' monthly household income is as follows: less than 10,000 Yuan (1,277 EUR) (31%), 10,000–20,000 Yuan (1,277–2,554 EUR) (41%) and 20,000–30,000 Yuan (2,554-3,830 EUR) (18%). The survey comprises a higher proportion of male and middle-aged participants compared to the statistics of the Composite Transportation Survey for the Fifth Time in 2017, likely because these individuals are more receptive to participating in the face-to-face survey on-site. The income distribution closely aligns with the statistical data. Most travellers are staff at government institutions and public research institutions or freelancers, constituting 22% and 31% respectively. Approximately 47% of the respondents indicate a general familiarity with the area, while 44% claim to be very familiar with it. The majority of travellers report having one or two persons in their car, accounting for 46% and 34%, respectively. In terms of the estimated parking time, 64% of the respondents expect to park for less than 30 minutes, while 15% anticipate a parking duration between 0.5 and 1 hour. Travellers' walking distance after parking is primarily within 100 m, accounting for 86% of the respondents.

Regarding psychological features that influence travellers' on-street parking decisions during the cruising process, 73% of respondents believe that there may be some empty parking spaces near their destination. Furthermore, 32% of respondents express concern about not finding any empty parking spaces ahead, while 38% make their parking decisions based on the situation they encounter during the cruising process. As for travellers who have parked their cars, the primary psychological state behind choosing the current on-street parked position is "taking a chance", with 52% of respondents citing this as their primary motivation. When faced with finding a closer empty parking space after already parking, 67% of respondents do not experience regret, while 25% feel little regret. If travellers arrive at their destination only to find no empty parking spaces, 15% will circle back and cruise again, 49% will continue to search for parking spaces ahead and 25% will opt to park anywhere with available space.

4. TRAJECTORY ANALYSIS FOR CRUISING AND PARKING PROCESS

To describe the fluctuations in vehicle trajectories during the cruising and parking processes, the fluctuation values for cruising trajectory $Vol(tra)$ and driving speed $Vol(V)$ were proposed. The higher the fluctuation value, the more pronounced the variations in the cruising trajectory and driving speed. The mathematical representation is as follows:

$$Vol(tra) = \frac{\sum_{i=2}^{n} |(y_i - y_{i-1})/(x_i - x_{i-1})|}{n-1} \quad (1)$$

$$Vol(V) = \frac{\sum_{i=2}^{n} |(v_i - v_{i-1})/(x_i - x_{i-1})|}{n-1} \quad (2)$$

where: x_i represents the horizontal distance from point i on the trajectory to Youshige. v_i is the speed at point i. y_i denotes the vertical distance from point i to the outer edge of the on-street parking space. n is the total number of points in each trajectory.

Upon analysing the trajectories of passing vehicles, it was observed that these car travellers tended to drive near the central line of the motorised lane, maintaining an average driving speed of approximately 23 km/h. Utilising parking location information, occupancy status of parking spaces and vehicle interferences, we categorised vehicle trajectories and thoroughly discussed the cruising characteristics of on-street parking.

4.1 Analysis of cruising and parking process for vehicles parked in on-street parking spaces

In this section, we analyse the cruising process and psychological states of vehicles parked on the street under both relatively saturated and unsaturated parking occupancy conditions.

Trajectory analysis under saturated on-street parking occupancy condition

In this study, we define a relatively saturated parking condition as one where the average parking occupancy on the road section passed by a car traveller exceeds 80%. In these conditions, 25 representative vehicle trajectories that had matching questionnaire data were chosen to analyse the characteristics of the cruising process and psychological features. Notably, only 48% of these vehicles experienced disruptions from other motorised or non-motorised vehicles, with each vehicle encountering less than three disturbances. Consequently, we classify the impact of these disturbances as "Small interference".

In the following three-dimensional figures, the horizontal axis signifies the direction of the vehicle's movement along the relief road towards Youshige. x=0 indicates the location of Youshige. The vertical axis, on the other hand, represents a direction perpendicular to the relief road. Here, y=0 designates the outer edge of the on-street parking space. Furthermore, y=1.5 signifies the demarcation line separating the non-motorised lane from the motorised lane, while y=3.25 marks the central line of the motorised lane.

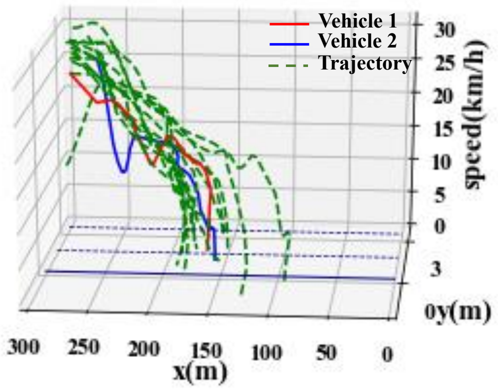


Figure 4 – Vehicle trajectories under relatively saturated parking occupancy condition

As depicted in *Figure 4*, representative samples under relatively saturated on-street parking occupancy conditions are presented. It is evident that the vehicle trajectories gradually shift towards the roadside during the cruising and parking processes as they approach their final parking positions. Furthermore, their driving speeds decrease gradually as well. In such saturated conditions, with small interference, most vehicle trajectories exhibit slight fluctuations, with an average trajectory fluctuation value of 0.023, as reflected in *Table 2*. Additionally, the average fluctuation value in driving speed is 0.231, with these vehicles travelling at a mean speed of 18 km/h. Generally, their chosen parking locations are far from the destination.

Based on the questionnaire data matched with vehicle trajectories, the majority of car travellers in this group are categorised as short-term on-street parkers, with an average parking duration of approximately 70 minutes. Under relatively saturated parking conditions, 60% of them express anxiety about encountering no available parking spaces ahead and opt to park as soon as they see an available place. This behaviour is exemplified by Representative Vehicle 1, which displays a small trajectory fluctuation value of 0.01, a short parking duration of 0.5 to 1 hour and a vehicle occupancy of two persons. Additionally, several travellers hold the cruising psychology of taking chances in selecting parking locations, leading to significantly fluctuating trajectories and lower average driving speeds. An illustration of this is Representative Vehicle 2, with a trajectory fluctuation value of 0.04 and an average driving speed of approximately 14 km/h.

Trajectory analysis under unsaturated on-street parking occupancy condition

Under unsaturated conditions, where the average parking occupancy on the relief road section is less than 80%, 41 vehicles were selected to analyse car travellers' cruising and parking behaviour with small and large interferences.

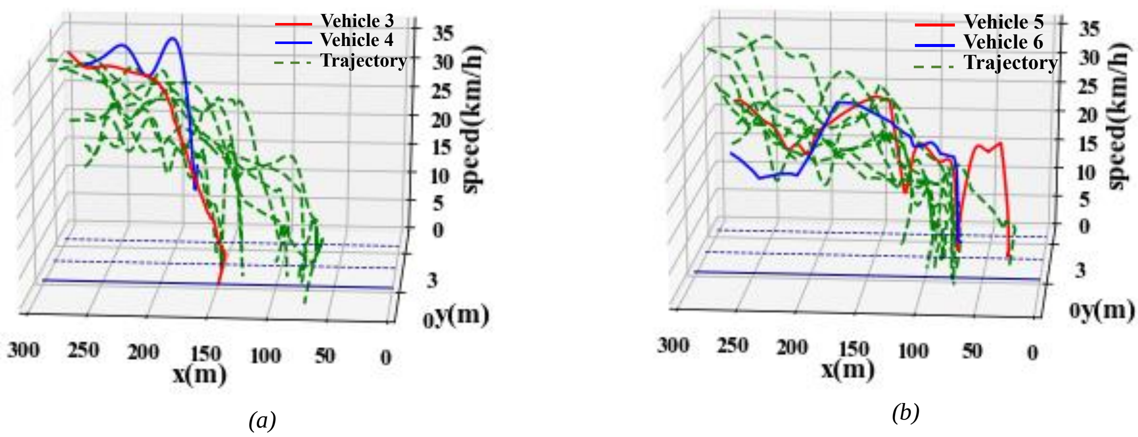


Figure 5 – Vehicle trajectories under relatively unsaturated parking occupancy conditions: a) with small interference; b) with large interference

Compared to the analysis conducted under relatively saturated on-street parking conditions, *Figure 5* illustrates that the vehicle trajectories and speed curves undergo significant fluctuations under relatively unsaturated parking conditions. Car travellers seem hesitant to make a decision, unsure whether to park immediately upon encountering an empty space or to continue cruising in search of a closer one to their destination. With small interference, the average fluctuation values for the cruising trajectories and driving speed are 0.026 and 0.306 respectively, as shown in *Table 2*, leading to an average speed of approximately 19 km/h. However, with large interferences, these values increase to 0.030 and 0.429, respectively, resulting in a lower average driving speed of around 17 km/h.

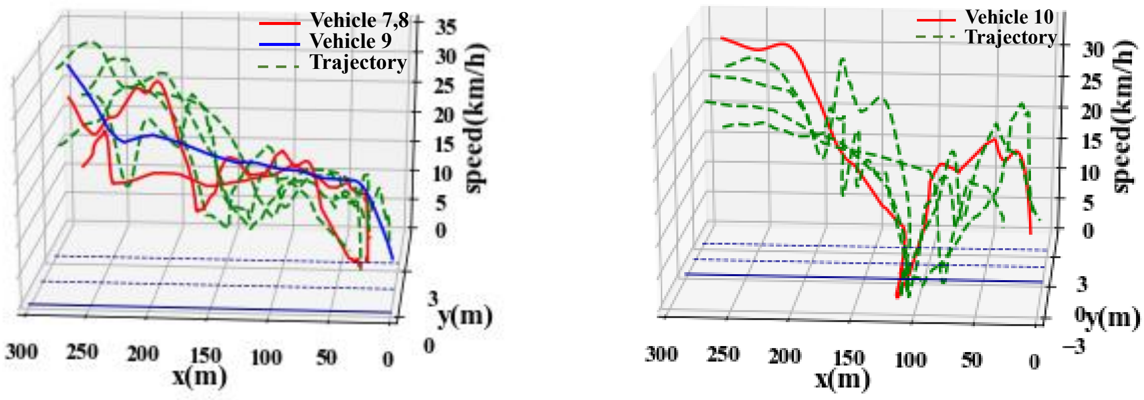
According to the matching questionnaire data, travellers in this group exhibit a shorter average on-street parking time of 45 minutes. Most car travellers try their luck to find a parking space and believe that there may be parking spaces ahead. Additionally, 50% of the respondents express no regret upon finding an empty parking space near their destination after parking. Representative Vehicles 3 and 5 in *Figure 5* are two examples of this behaviour. On the other hand, some car travellers search for parking places depending on the situation, as evidenced by Vehicles 4 and 6.

4.2 Analysis of cruising and parking process for vehicles parked outside parking spaces

Trajectory analysis for parking once

During the driving process, some car travellers encounter vacant parking spaces but opt not to use them. Instead, they illegally park in front of Youshige due to the unavailability of nearby parking spaces. This behaviour is observed in approximately 20% of travellers and 40 vehicle samples were selected for a comprehensive analysis of their cruising and parking processes.

Figure 6a illustrates that the fluctuations of vehicle trajectories for representative samples parked outside the parking spaces are relatively small. The average fluctuation values for trajectory and speed are 0.019 and 0.281, respectively, as shown in *Table 2*.



(a) *(b)*

Figure 6 – Trajectories for vehicles parked outside on-street parking spaces: a) parking once; b) parking twice

The average parking time for travellers in this group is approximately 10 minutes. Most of them temporarily park to pick up or drop off persons. They prefer to park closer to their destination and would rather park illegally if no parking spaces are available upon arrival. In terms of the psychological state influencing their decision-making, 82% of the car travellers in this group express that they are willing to take risks when searching for parking, anticipating that they will find vacant spaces near their destination, as evidenced by the behaviour of Representative Vehicle 7. Additionally, some travellers, particularly those with more passengers in the car, primarily rely on past parking experiences when cruising. They do not regret finding an empty parking space ahead after already parking. As demonstrated by Vehicle 9, which carried three persons, the traveller opts to park outside on-street parking spaces at the destination if no parking spaces are available.

Trajectory analysis for parking twice

Several car travellers park their cars twice along the road section. Initially, they park far from their destination for a brief period of less than 3 minutes. Subsequently, they continue driving and park outside the parking space in front of Youshige. Five representative vehicles that parked twice were selected for the analysis of their cruising and parking processes.

As depicted in *Figure 6b*, these travellers exhibit significant fluctuations in vehicle trajectories and driving speed curves due to their decision to park twice. The average fluctuation values for trajectory and speed are 0.080 and 0.642, respectively, as shown in *Table 2*, for a short parking duration. The psychological state during parking decision-making primarily relies on luck to find a parking space. If they reach their destination and discover no available parking spaces, they resort to illegal parking in open areas. For instance, Vehicle 10 demonstrates this behaviour with a parking duration of 15 minutes. Additionally, the cruising and parking behaviour of car travellers within this group significantly impacts road traffic.

To address the issue of illegal parking, establishing temporary parking areas can be an effective solution for promoting legal parking within commercial complexes. These areas can be designated for short-term parking, with signs indicating a time limit of 10–15 minutes. The number of temporary parking spaces can be set at approximately 20% of the total parking demand.

Table 2 outlines the statistical characteristics and psychological states associated with different cruising processes under differing conditions.

Table 2 – Statistical characteristics and psychological state of the cruising process

Parking location	Parking condition	Fluctuation values of trajectory	Fluctuation values of speed	Main psychological state for cruising
Park in on-street parking spaces	- Saturated parking - Small interferences	0.023	0.231	Worry about finding no parking space ahead and park as soon as see a vacant space
	- Unsaturated parking - Small interferences	0.026	0.306	- Take a chance for cruising and think that there might be parking spaces ahead - Cruise depending on the situation
	- Unsaturated parking - Large interferences	0.030	0.429	
Park outside on-street parking spaces	Parking once	0.019	0.281	- Take a chance for cruising and anticipate finding vacant parking spaces near the destination - Park illegally if no parking spaces are available at the destination
	Parking twice	0.080	0.642	

5. ANALYSIS OF CRUISING AND PARKING PROCESS BASED ON SEM

The cruising process for on-street parking may demonstrate different characteristics based on personal attributes, parking behaviour and psychological states of travellers. However, some influencing factors cannot be accurately quantified using traditional statistical methods. The structural equation model (SEM) is an essential tool for analysing multi-source data and overcoming this limitation [22]. Furthermore, SEM enables the examination of relationships between latent variables and effectively explains the issue of variables with measurement errors. Therefore, we utilise SEM to analyse the relationship between the cruising process for parking and its influencing factors.

5.1 Structural equation model

Structural equation modelling (SEM) is a statistical method employed to represent, estimate and test the relationships between variables, including both measured variables and latent constructs. The model is frequently depicted as a diagram, facilitating the specification and analysis of relationships between variables based on the covariance matrix [23].

SEM comprises measurement and structural models. The measurement model consists of latent and observed variables. A latent variable is not directly or precisely measurable and must be inferred from the data collected through observed variables. In contrast, a measured variable can be directly measurable. The structural model illustrates the diagrammatic representation of the relationships between latent variables. Latent variables can be classified into extrinsic and endogenous latent variables, depending on their causality.

Equation 3 represents the structural model used to analyse the relationships between latent variables. Meanwhile, *Equations 4 and 5* serve as measurement models, depicting the relationships between latent variables and observed variables.

$$\eta = B\eta + \Gamma\xi + \zeta \tag{3}$$

$$Y = \Lambda_Y \eta + \varepsilon \tag{4}$$

$$X = \Lambda_X \xi + \delta \tag{5}$$

where η is the vector of endogenous latent variables. B is the coefficient matrix of endogenous latent variables. ξ is the vector of exogenous latent variables. Γ is the coefficient matrix of exogenous latent variables. ζ is the residual vector. Y denotes a vector of observed endogenous variables. Λ_Y is the matrix of structural coefficients for latent endogenous variables based on their observed endogenous variables. ε is the vector of measurement error for endogenous variables. X is the vector of observed exogenous variables. Λ_X is the matrix of structural coefficients for latent exogenous variables based on their observed variables. δ is the vector of measurement error for exogenous variables.

The SEM analysis involves several steps, including theoretical model construction, quantification of variables, model identification, evaluation and modification. The process of fitting data using structural equation modelling is dynamic and continuously evolving, necessitating adjustments to the model's structure based on experience and previous fitting results. This iterative approach can ultimately enable the derivation of the most reasonable model that aligns with empirical evidence. In this study, maximum likelihood estimation (MLE) is utilised for model estimation [24]. Moreover, the AMOS software, with its graphical interface, offers convenience for parameter estimation in SEM.

5.2 Selection of variables for SEM

Using the factor analysis method, eight factors influencing on-street parking behaviour were preliminarily identified, as outlined in *Table 3*. Personal information includes gender, monthly household income and occupation. Factors related to parking encompass the expected parking time and the number of persons in the car. Psychological factors that affect parking decisions involve the individual's psychological state during the cruising process and the selection of the current parking location, and the degree of regret experienced upon finding a vacant parking space near the destination after parking. The characteristics observed during the cruising and parking process encompass fluctuations in vehicle trajectory and cruising speed curves, and the current parking location. Additional factors taken into consideration are the degree of vehicle interference and parking space occupancy. The latent variables for the structural equation model were designated as personal information, factors related to parking, cruising psychology and the characteristics of cruising and parking processes.

Table 3 – Variables in the structural equation model

Latent variables and other factors	Observed variables	Identifier	Description
Personal information (F1)	Gender	X_{11}	Male: 1; Female: 2
	Monthly household income	X_{12}	Continuous variable
	Occupation	X_{13}	Governmental, technical and management personnel: 1; Others: 2
Factors related to parking (F2)	Expected parking time	X_{21}	Continuous variable
	Number of persons in the car	X_{22}	Continuous variable
Cruising psychology affecting parking decision (F3)	Psychological state during the cruising process	X_{31}	Worrying about no parking space ahead: 1; Depending on the situation: 2; Relying on past parking experiences: 3
	Psychological state influencing the choice of the current parking location	X_{32}	Take a chance: 1; Believe that there must be empty parking spaces here: 2; Relying on parking experiences: 3; Others:4
	Degree of regret	X_{33}	No regret at all: 1; A little bit of regret: 2; Very regretful: 3

Latent variables and other factors	Observed variables	Identifier	Description
Characteristics of cruising and parking process (F4)	Fluctuation of trajectory	X_{41}	Continuous variable
	Fluctuation of cruising speed	X_{42}	Continuous variable
	Cruising speed	X_{43}	Continuous variable
	Parking location	X_{44}	In parking space: 1; Outside parking space: 2
Other factors	Vehicle interferences	X_{51}	Small interferences 1; Large interferences: 2
	Average parking occupancy on the relief road	X_{52}	Unsaturated: 1; Relatively saturated: 2

5.3 Model estimation and analysis

In the SEM estimation, the symbol "e" is utilised to signify the residual and measurement error of ζ, ε, and δ within the AMOS software. The standardised output results of the SEM for cruising behaviour analysis are presented in *Figure 7*.

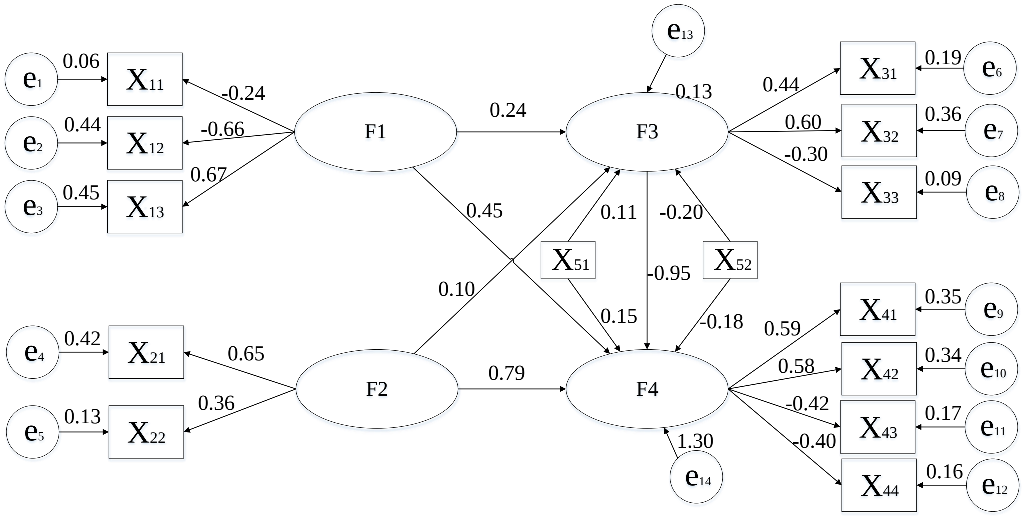


Figure 7 – Standardised results of model estimation

The goodness-of-fit statistics for the SEM are presented in *Table 4*. The chi-square and degrees of freedom (CMIN/DF) are 0.939, which is less than 3. The goodness-of-fit index (GFI), adjusted goodness-of-fit index (AGFI), comparative fit index (CFI) and incremental fit index (IFI) are 0.948, 0.909, 0.968 and 0.976, respectively, all exceeding the recommended threshold of 0.9. The root mean square error of approximation (RMSEA) is 0.000, which is less than 0.08. It is evident that the model indices meet the standard or critical values, indicating that the model is acceptable and provides a better fit for the data [25].

Table 4 – Fit indices of the model

Fit indices	Description	Value	Fit standard
CMIN/DF	Chi-square /degree of freedom	0.939	<3
GFI	Goodness-of-fit index	0.948	>0.9
AGFI	Adjusted goodness-of-fit index	0.909	>0.9
CFI	Comparative fit index	0.968	>0.9
IFI	Incremental fit index	0.976	>0.9
RMSEA	Root mean square error of approximation	0.000	<0.08

The coefficients of gender, monthly household income and occupation on the latent variable of personal information are -0.24, -0.66 and -0.67, respectively. The latent variable for personal information is primarily reflected by the factors of income and occupation. The coefficients for the psychological state during the cruising process, the choice of parked location and the degree of regret upon finding a parking space near the destination after parking, on the latent variable of on-street cruising psychology are 0.44, 0.60 and -0.30, respectively. Psychological states for the cruising process and the choice of parked location have a relatively large impact on cruising psychology. Additionally, the coefficients for parking time and the number of persons in the car on the latent variable of parking behaviour are 0.65 and 0.36, respectively, suggesting that these two factors are key indicators of travellers' parking characteristics. The coefficients for the fluctuation of trajectory and cruising speed, and parking location on the latent variable of characteristics for cruising and parking process are 0.59, 0.58, -0.42 and -0.40 respectively. This indicates that the characteristics of the cruising and parking process can be reflected by the observed process information of cruising for parking.

The load coefficient between the latent variables of cruising psychology and the characteristics of the cruising and parking process is the highest, with a value of -0.95, implying a strong correlation. Travellers who worry about no parking space ahead or take a chance to make a parking decision and express great regret for their choice when they find an empty parking space very near the destination after parking, exhibit higher trajectory fluctuations and drive at lower speeds during the cruising and parking process. They primarily opt to park their cars in on-street parking spaces. In contrast, travellers who base their on-street parking decisions on past experiences and do not regret missing closer parking spaces, experience lower trajectory fluctuations and drive at higher speeds. Overall, to alleviate traffic problems caused by cruising for parking, providing real-time parking information can be an effective strategy. This approach can help reduce anxiety and regret, leading to greater psychological certainty during the cruising process. As a result, it can decrease trajectory fluctuations and increase driving speeds, ultimately improving the overall traffic flow.

The load coefficient between the latent variables of factors related to parking, and cruising and parking process characteristics is higher, with a value of 0.79. Travellers who have longer parking time and more persons in their car exhibit higher trajectory fluctuation and lower driving speed during the on-street cruising process and tend to park their cars in on-street parking spaces. The load coefficient between personal information and the characteristics of the cruising and parking process is -0.45. Specifically, middle- and upper-income groups who work in government, public research institutions and enterprises display lower trajectory fluctuation and higher cruising speeds.

5.4 Analysis of the direct and indirect effects of factors on the cruising and parking process

Additionally, the direct effects of cruising psychology and factors related to parking on the characteristics of the cruising and parking process are more significant than those of personal information. This suggests that psychological and parking features are the primary factors influencing the cruising process for parking. Furthermore, the interference between motorised and non-motorised vehicles has a load coefficient of 0.15 on the cruising process, suggesting that greater interference leads to higher trajectory fluctuations and lower speeds. The average parking occupancy on the road that vehicles pass by has a load coefficient of -0.18 on the cruising process. This indicates that a saturated parking situation results in lower trajectory fluctuation and higher speeds, potentially leading to illegal parking.

Table 5 – The direct and indirect effects of latent variables on the cruising process

Latent variables and other factors	**Characteristics of the cruising and parking process**		
	Direct effect	**Indirect effect**	**Total effect**
Personal information	0.45	-0.23	0.22
Factors related to parking	0.79	-0.10	0.69
Cruising psychology	-0.95	—	-0.95
Vehicle interferences	0.15	-0.10	0.05
Average parking occupancy on the relief road	-0.18	0.19	0.01

Table 5 illustrates that personal information and factors related to parking can indirectly influence the cruising process through the mediation of cruising psychology. The indirect effect of personal information on cruising characteristics is -0.23, suggesting that individual differences partially affect the cruising process through the influence of cruising psychology. For instance, some low-income travellers, as well as freelancers or individuals with other occupation types are more likely to make parking decisions based on past experiences, thereby contributing to the cruising process. Similarly, the indirect effect of factors related to parking on cruising characteristics is -0.10. This indicates that travellers with more persons in their cars and longer parking times tend to be more cautious in their decision-making, which in turn impacts the cruising and parking processes.

Furthermore, the indirect effect of the average parking occupancy a car traveller passes by on cruising characteristics is 0.19. This indicates that a saturated parking situation can cause car travellers to worry about having no parking spaces ahead or to take chances while cruising for a parking space. These findings underscore the significant relationship between psychological factors and behavioural characteristics in the cruising and parking process. Consequently, targeted traffic policies that take into account individual and parking characteristics, as well as cruising psychology, can be more effective in influencing travellers' psychological states regarding parking decisions and then modifying car travellers' cruising behaviour. This, in turn, can mitigate the cruising phenomenon and reduce traffic congestion.

6. CONCLUSION

Due to the rapid increase in the number of motor vehicles, parking issues are becoming increasingly serious, particularly in central business districts. Cruising for parking significantly affects traffic efficiency. From both a procedural and psychological perspective, this study delves into travellers' cruising and parking processes utilising a concurrent video and questionnaire survey conducted along a road in Beijing. A structural equation model was then employed to further examine the relationship between the cruising process for parking and psychological factors. The findings are summarised as follows.

Based on the vehicle trajectory data, fluctuation values were proposed to characterise the changes in cruising trajectory and driving speed during the cruising and parking process. In relatively saturated on-street parking occupancy conditions with small interferences, most vehicle trajectories and speed exhibit slight fluctuations, accompanied by a higher average speed, leading to a small effect on road traffic. In these conditions, relatively longer-term parkers often opt for spaces farther from their destination due to concerns over the limited availability of parking spaces near their destination. Conversely, under relatively unsaturated on-street parking occupancy conditions, vehicle trajectories and speed curves demonstrate greater variability. Furthermore, the average fluctuation values are higher in situations with large interferences compared to those with small interference. In these contexts, many travellers exhibit a reliance on chance and appear hesitant in deciding whether to immediately park upon encountering an empty space or continue cruising in search of a closer one.

For travellers who choose to park their cars outside the on-street parking spaces, they typically do so for brief periods, often to pick up or drop off persons. Their average parking time is approximately 10 minutes. These individuals generally anticipate the availability of empty parking spaces at their destination and prefer to park as close as possible. However, when no vacant parking spaces are available upon arrival, they resort to illegal parking. Several car travellers even park their cars along the road section twice, significantly impacting road traffic through their cruising and parking activities. Consequently, it is essential to establish temporary parking areas to accommodate approximately 20% of the parking demand. Furthermore, implementing temporary parking signs with time limits of 10–15 minutes can be an effective measure to encourage legal parking within commercial complexes.

The estimation results from the structural equation model (SEM) suggest that the model provides a good fit for the data. Psychological and parking-related factors have notable impacts on cruising characteristics. Travellers exhibit concerned and hesitant psychological states, such as taking chances when making parking decisions, and tend to experience higher trajectory fluctuation and lower speeds during the cruising and parking process. Certain influencing factors indirectly affect cruising characteristics through the mediation of psychological factors. For instance, individuals with low incomes, freelancers and those in other occupations are more inclined to make rational parking decisions based on their past parking experiences, thereby contributing to the cruising process. Additionally, travellers with more persons in the car and longer parking durations tend to exercise greater caution when making decisions, subsequently influencing their cruising and parking processes.

On-street parking primarily serves parking users, with the parking time falling within 1 hour. These conclusions underscore the significant relationship between psychological factors and behavioural characteristics during cruising and parking processes. Therefore, targeted traffic policies grounded in different cruising psychological analyses can be more effective in mitigating cruising phenomenon and traffic congestion. For travellers who hesitate to make a decision to park immediately or continue to cruise, and who worry about no parking space ahead, providing real-time parking information and guiding them to park can be an effective strategy. This approach can help alleviate psychological certainty during the cruising process, resulting in lower trajectory fluctuations and faster driving speeds. For travellers who take risks in searching for parking, preferring to park closer to their destination and resorting to illegal parking when no spaces are available, establishing temporary parking areas with a time limit for short-term parking can be an effective solution for promoting legal parking. Additionally, implementing an intelligent parking violation monitoring system and imposing fines for illegal parking can further enhance the effectiveness of promoting legal parking practices. Reasonably planning and allocating on-street parking spaces and non-motorised lanes can reduce the interferences caused by on-street parking and non-motorised vehicles and overall traffic conditions.

Additionally, the research method and conclusions in this study can be expanded to identify and predict travellers' parking location and parking status at the destination in advance. The predicted results can be helpful in formulating suitable parking information release and guidance strategies, thereby modulating travellers' parking decisions and mitigating the negative impact of cruising for parking on road traffic.

Future research could focus on enlarging the sample size of cruising vehicles that do not park along this road section and instead continue to cruise. This expansion would facilitate the development of a more robust and reliable model for examining cruising characteristics for parking. Additionally, extending the combined video survey and questionnaire survey to a broader regional network encompassing more road sections would be advantageous. Such an expansion would enable the collection of comprehensive data on the entire cruising and parking process of vehicles, along with parking features, fostering a deeper understanding of the relationship between influencing factors and the cruising process for parking. Furthermore, our future study aims to incorporate a comparative analysis of the cruising behaviour of travellers who opt for on-street parking versus off-street parking.

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路内停车寻泊过程和心理决策研究

秦焕美, 庞千千, 成美娜, 韩艳

摘要

停车供需不平衡所带来的停车寻泊现象，常常会影响道路交通运行。为了解决这些问题，基于在北京开展的路内停车视频和问卷调查，从过程和心理的角度，建立结构方程模型探讨心理因素与停车寻泊特征之间的关系。结果表明，在不同情况下，出行者具有不同的停车巡航停车特征。当路内停车位利用率不高的情况下，出行者

的停车寻泊轨迹呈现出更大的波动性，在做出停车停车决策时会犹豫不决。相反，在路内停车泊位利用比较饱和的情况下，出行者的停车寻泊轨迹波动性较小，其寻泊心理主要是担心前方没有停车位。短时停车者通常希望将车停在离目的地更近的地方，如果目的地车位已满，他们会选择非法停车。心理和停车相关因素会直接对路内停车寻泊特征产生重要的影响，同时，个体差异、停车特征和停车泊位利用状况也会通过心理因素间接影响停车寻泊过程。因此，可以根据不同的停车寻泊心理分析制定有针对性的政策，以影响出行者的停车决策，减轻停车寻泊对道路交通造成的负面影响。

关键词
车辆轨迹；寻泊和停车过程；寻泊心理；结构方程模型