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Research Article

Commuter Travel Behavior Modeling in Metropolitan Areas Based on Cumulative Prospect Theory: A Case Study of Xi'an, China

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A metropolitan area is a new form of urban development under the agglomeration effect and scale economy. The renewal and upgrading of urban spatial structures have brought new pressure to urban commuting. Under the new form of the metropolitan area, the process of regional integration has accelerated, and long-distance extreme commuting has increased. New changes have taken place in the travel structure. This paper constructs a travel behavior selection model for office workers based on the cumulative prospect theory, introduces the value of commuting travel time into the generalized travel cost function, uses the weight function and the improved generalized travel cost function as the basis of the transportation mode selection model, defines the reference point of the generalized travel cost in the model, and selects the prospect with the largest cumulative prospect value as the optimal decision for travelers. Based on the "expected utility maximization theory" and the "cumulative prospect theory," the commuter is simulated under four different travel scenarios to study the optimal traffic mode selection behavior. The results show that under the framework of expected utility theory, the travel mode choice behavior of commuters is not affected by travel scenarios, and the cumulative prospect theory is more suitable for the study of travel mode choice behavior. The construction of a transportation mode selection model with the value of commuting travel time as the core variable can help commuters to choose a reasonable transportation mode and provide a basis for the government and relevant departments to formulate traffic management plans and implement traffic congestion mitigation policies.

1. Introduction

The formation of the metropolitan area results from the collection of urban energy and distribution at a certain stage and the process of gathering the population toward the center. With the stability of the urban nuclear population scale, the outer circle layer becomes the concentrated carrier of the new population and even forms a ring structure surrounding the city at the periphery of the urban arena. The pressure of land premium and population saturation in the central city makes the urban center and industrial initiatives in the city move outward to the edge of the urban area, and the employment position changes from extremely concentrated to multicenter distribution. It will inevitably lead to the expansion of the scale of travel demand, which will lead to the increasingly prominent imbalance between the rapid increase of traffic demand and the insufficient traffic supply, and then evolve into a series of social problems, namely, the dislocation of work and living space, the long commute, and the reduction of employment rate. At the same time, the pursuit of efficient travel by urban residents has led to the continuous growth of the number of motor vehicles and the increasing saturation of urban roads, and the overall traffic congestion in major cities has become a common problem in major cities.

As the size of the city grows and travel distance increases, people's demand for the speed of transportation tools increases. Consequently, the characteristics of the distance traveled by urban residents objectively directly determine the proportion of travel volume that the various modes of transport can share, that is, a reasonable transport structure. On the other hand, because people have a tolerable limit on travel time consumption of a certain mode of transportation, urban residents will inevitably choose the mode of transportation according to the transport time consumption provided by different modes of transportation to ensure that travel time consumption is within an acceptable range. In the urban transport system, with the improvement of personal income, there are also cross demands between individual and public transport: the comfort of individual transport, door-to-door service advantages, and people who meet the needs of high-quality transport travel.

Therefore, this article combines the process of complex travel choice behavior with the psychological state of commuters, fully considering simulated scenarios of commuter travel behavior, assuming departure time, congestion probability, and possible commuting time consumption, constructing a travel mode selection model, calculating cumulative prospect values and perceived travel costs, and exploring the direction of guiding travel behavior by comparing the differences in optimal results under different theoretical frameworks.

2. Related Work

The arrival of the era of metropolitan area has catalyzed the explosive growth of traffic demand. The proportion of individual traffic trips has increased. Most large and medium-sized cities are still in the high-speed period of population mobility. The urban disposable traffic resources are in a state of high load for a long time. The proportion of supply and demand is seriously unbalanced. The urban congestion is serious, which has become a bottleneck restricting the regional economic growth and the establishment of a high-quality regional development pattern.

After the 20th century, with the acceleration of urbanization, a large number of scholars put forward the development trend and types of metropolitan areas and generally believed that the evolution of metropolitan areas and the development of urban transportation had interaction, mutual promotion and mutual influence. Muller [1], based on the experience of urban development in the United States, believes that the urban transportation system and the spatial form of metropolis are a model of mutual continuous promotion and growth. Waddell et al. [2] believe that urban traffic is constantly adjusting with the evolution process from single center to multicenter in the metropolitan area, so it demonstrates that there is a high degree of interaction between urban form and its transportation system. Thapa and Murayama [3] deduced that in the future, the urban development of Kathmandu Valley will continue to expand through the filling of existing urban areas and will be greatly affected by the existing urban space and transportation network. Jun [4] analyzed the time change of urban morphology and individual commuting behavior in Seoul Metropolitan Area from 2000 to 2015 and revealed that the improvement of public transport accessibility and the emergence of new suburban subcenters have reduced some commuting time relatively, but these new suburban subcenters have also attracted more workers from the broader employment market, leading to longer commuting time for commuters in suburban subcenters.

In terms of travel mode selection and optimization, most existing studies have conducted empirical research based on mathematical models in economically developed cities and regions. For example, Koppelman and Wen [5] established a logit model based on travel mode based on the stochastic utility maximization method. Li and Lu [6] established a differential equation model to adjust the travel structure from three aspects: limiting the intensity of competition, improving the competitiveness of public transport, and controlling the traffic growth rate. Dezani [7] realized the optimization of traffic flow by positioning vehicles in route planning. Wang and Sun [8] established a dynamic game model of traffic competition to adapt to the goal of achieving a reasonable traffic structure in historical districts. Li Taking Norway as an example, Næss [9] found that reducing travel distance, promoting better transportation supply, and levying urban road tolls can effectively save land and reduce car travel. Deng and Zhao [10] found that the subway system affects urban development in many aspects. Choosing urban transportation between subway dominance and car dominance is the result of competition between subway development and car popularity. In future urban development, the urban subway network can respond to the needs of the city in a layered manner.

Through reviewing existing literature, it has been found that previous studies have paid less attention to the impact mechanism of urban agglomeration spatial structure on individual travel behavior. In terms of empirical research, data sources are mainly concentrated in more mature regions, and there is a lack of attention to urban agglomerations in their embryonic and emerging forms, especially in newly approved urban agglomerations in the central and western regions. Meanwhile, in the study of individual travel behavior, there are few studies that directly focus on daily commuters, and further verification and analysis are still needed.

3. Travel Choice Model for Office Workers Based on Cumulative Prospect Theory

3.1. The Theoretical Model of Cumulative Prospect Theory. Prospect theory is a bounded rationality model hypothesis that takes into account cognitive privacy in psychology. Unlike previous decision-making research on travel behavior, the early rational economic man hypothesis pursued maximization principles and did not take into account individual attitudes and cognition towards different outcomes, which has certain limitations [11]. Therefore, applying the cumulative prospect theory to analyze the mechanism of travel behavior choice is closer to real-life situations compared to the assumptions of rational individuals. Based on this, constructing a travel mode choice behavior model can better describe individual psychological characteristics.

This theory is widely applied to study attitudes towards gains and losses in decision-making. The main content of this theory is that, in the absence of accurate risk assessment, an individual's behavioral decision-making is determined by the difference between the outcome and the preconceived idea. Among them, decision-making is composed of a value function and a decision weight function, which assumes that the uncertain decision-making process can be divided into two stages: editing and evaluation. Decision-makers differentiate value into gains and losses based on reference points, and changes in gains and losses can alter people's subjective perception of value, thereby influencing and changing their preferences. In the evaluation stage, we replace the utility function in the expected utility theory with a value function, replace the probability of the expected utility function with the decision weight of the weight function, and make decisions based on changes in value rather than current value.

3.2. Theoretical Model Establishment. By using the cumulative prospect theory to analyze the mechanism of travel behavior choice, a travel mode choice behavior model can be constructed, which is also divided into two stages. The first stage is to define the value function and weight function of each travel mode, that is, the editing stage. The second stage is to comprehensively consider the value function and weight function corresponding to different travel modes, assign them different utility values, calculate the prospect value of each travel possibility, and use the maximum prospect value as its decision result, thus producing decision-making behavior, that is, the evaluation stage [12].

3.2.1. Value Function. Cumulative prospect theory points out that people's decision-making behavior meets reference point dependence, and the selection of reference points directly determines the subjective perception of an event by individual decision-makers [13]. In this paper, travel cost and travel time are selected as the reference points of the model. The value function is the perceived value used by travelers to describe the actual loss or gain that may occur as a result of their own travel mode choice. The reference points set in this article are acceptable waiting times have three values. They are, respectively, 40 min, 50 min, and 60 min. Different travel modes are in different loss or gain states under different reference points, resulting in different perceived values of travel modes. Different travel modes are in different loss or gain states under different reference point values, which lead to different perceived values of different travel modes. Formula (1) is the specific value function of traveler's travel mode selection behavior, where x is the difference between the time needed for commuters to choose a certain commuting mode and the acceptable time, and the positive and negative values of x are the "gain" and "loss" caused by this commuting mode.

$$V(x) = \begin{cases} x^{\alpha}, & x \geq 0, \\ -\rho(-x)^{\beta}, & x < 0. \end{cases} \tag{1}$$

3.2.2. Determination of Decision Weight Function. The decision weight function $Q(k)$ is the subjective judgment function of travelers to the possible results k of each travel mode, and it is a weighted function of the probability of event occurrence [14]. The formula expression of the decision weight function is shown in formula (2), and the parameters θ and μ are the attitude coefficients facing different results, respectively. If $\theta > 1$, it means that commuters are more sensitive to the loss, meaning that commuters find the loss more unbearable.

$$\begin{cases} Q(k)^{+} = \dfrac{k^{\theta}}{\left[k^{\theta} + (1-k)^{\theta}\right]^{1/\theta}}, \\ \\ Q(k)^{-} = \dfrac{k^{\mu}}{\left[k^{\mu} + (1-p_i)^{\mu}\right]^{1/\mu}}. \end{cases} \tag{2}$$

3.2.3. Evaluation Stage. The accumulated prospect value is the basis for travelers to make the final choice of travel mode, and commuters are more likely to choose the travel mode with the largest accumulated prospect value as the decision result [15]. The cumulative prospect value $Q(k_i)$ is calculated by calculating the cumulative probability of a travel mode, and considering it and the value function comprehensively, the sum of the product of the two is the cumulative prospect value of the travel mode. The cumulative prospect value of a travel mode is as follows:

$$\mathrm{CPV}(x,k) = \sum_{i=0}^{n} V(x)\pi^{+}(p_i) + \sum_{i=-m}^{0} V(x)\pi^{-}(p_i). \tag{3}$$

The cumulative decision prospect function in the above equation is as follows:

$$\begin{aligned} \pi^{+}(p_i) &= W(p_i + \cdots + p_n) - W(p_{i+1} + \cdots + p_n); \quad 0 \leq i \leq n-1, \\ \pi^{-}(p_i) &= W(p_{-m} + \cdots + p_i) - W(p_{-m} + \cdots + p_{i-1}); \quad 1-m \leq i \leq 0. \end{aligned} \tag{4}$$

In this study, when faced with uncertain waiting time, travelers choose a travel mode φ among the four travel modes of subway, bus, private car, and new energy taxi, which can be expressed as follows:

$$\mathrm{CPV}_{\varphi} = \mathrm{Max}\left(\mathrm{CPV}_1, \mathrm{CPV}_2, \mathrm{CPV}_3, \mathrm{CPV}_4\right). \tag{5}$$

Obviously, the larger the comprehensive cumulative prospect value, the more consistent the travel mode is with the commuter's psychology, and the travel mode corresponding to the maximum comprehensive prospect value is the first choice of the commuter.

3.3. Generalized Travel Cost Function. The cost of commuters throughout the journey includes the cost of travel time and the cost of delays caused by arriving early or arriving late. The travel cost function of commuters is defined as formula (6), where C_{Early} is the cost of early arrival of commuters, C_{Late} is the cost of late arrival of commuters, and the Free_{φ} is transportation expenses to be paid for choosing different transportation modes:

$$\mathrm{TC}_{\varphi} = C_{\mathrm{Early}} + C_{\mathrm{Late}} + C_{\mathrm{Trip}} + \mathrm{Free}_{\varphi}. \tag{6}$$

4. Spatial Structure of Xi'an Metropolitan Area and Data Sources

4.1. Urban Development Process. A city as a regional economic center, the metropolitan area shows unprecedented attraction and radiation functions to the region. Under the influence of the "law of distance attenuation," the spatial structure of the metropolitan area has formed a regular hierarchical differentiation with the core city as the center and outward. According to the sequence and economic status of the city in the process of development, it is generally divided into three circles: the core circle, the close circle, and the fringe circle. The three circles radiate outward from the core circle. The core circle is the core area of the whole metropolitan area. The farther away from the core circle, the more difficult it is to absorb the economic dividends and development advantages brought by the core region. The specific urban development structure is shown in Figure 1.

In the whole circle structure, as the node of development and circle extension, the city not only has the characteristics of the circle structure but also because it is located in different geographical locations, leading to the formation of each circle state with its own characteristics in the development process. Generally, each city and region has a limited scope of influence on the surrounding circles, which is closely related to the size of the city, the accessibility of traffic, and the ability of external radiation, thus showing a hierarchical nature.

4.2. The Decision-Making Process of Individual Travel Behavior. Travel mode selection is a dynamic and complex activity. Each trip is a process and should be a complete and continuous process. The travel decision behavior can be regarded as a continuous chain decision process including several travel behaviors. The basic process of individual travel mode selection is to generate travel demand due to their own needs, determine the travel destination and travel time, use individual experience to determine the appropriate travel path based on comprehensive analysis according to travel distance, urban characteristics, traffic facility distribution, road condition information, vehicle characteristics, and personal preferences, and whether to choose parking and transfer during the travel process, and predict the utility of various travel modes to determine the travel mode that meets the requirements of this trip [16].

When facing a choice of commuting mode, commuters will make decisions according to the following steps: first, when the travel scenario and environment are uncertain, commuters will perceive the cost of each commuting mode and then calculate the total perceived travel cost of each commuting mode. Second, after collecting and processing relevant information, the commuter sets a reasonable travel reference point, uses the reference point as a measure, compares the perceived travel cost of each commuter mode with the reference point to see whether it is "benefit" or "loss," and calculates the "benefit value" and "loss value." Third, we bring the "profit and loss value" of each commuting mode into the value function to calculate the value of each commuting mode, and then calculate the weight value of each commuting mode, and then get the cumulative prospect value of each commuting mode, and evaluate the cumulative prospect value of each commuting mode. Fourth, after judging and comparing the commuting modes between the residence and the work place, we choose the mode with the maximum cumulative prospect value for commuting and finally complete the decision-making process, as shown in Figure 2.

4.3. Spatial Structure of Xi'an Metropolitan Area. The core area of Xi'an metropolitan area mainly includes the downtown area of Xi'an, namely, Xincheng District, Beilin District, Lianhu District, Yanta District, Baqiao District, Weiyang District, and Chang'an District, the main urban area of Xianyang City, and also includes Fengdong New City and Fengxi New City in Xixian New District. Therefore, the data acquisition scope of this paper is selected as Xi'an metropolitan area. On the one hand, it responds to the national policy support for the construction of the western region; on the other hand, based on the special conditions of the approval of Xi'an metropolitan area, the research results can also provide reference for the development of urban transportation and metropolitan area construction in the western region. At present, the traffic in Xi'an metropolitan area is still dominated by internal commuter traffic (Figure 3).

4.4. Data Sources. According to the minimum living security standard for urban residents of Xi'an from October 1, 2020, based on 740 yuan/month per person and the maximum standard of conventional family size, families with an annual household income of less than 50,000 yuan are defined as low-income families, and other families are classified as nonlow-

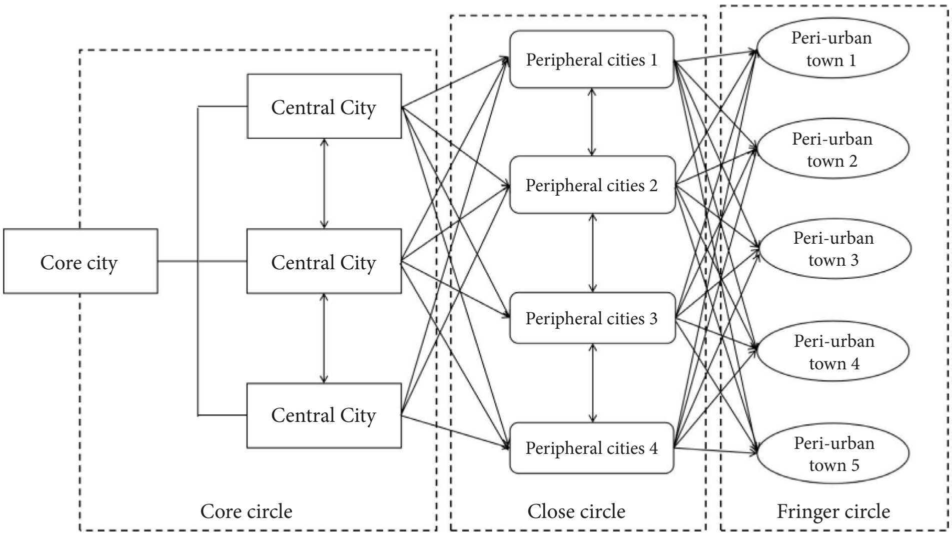

Figure 1: Schematic diagram of urban scale and structure of metropolitan area.

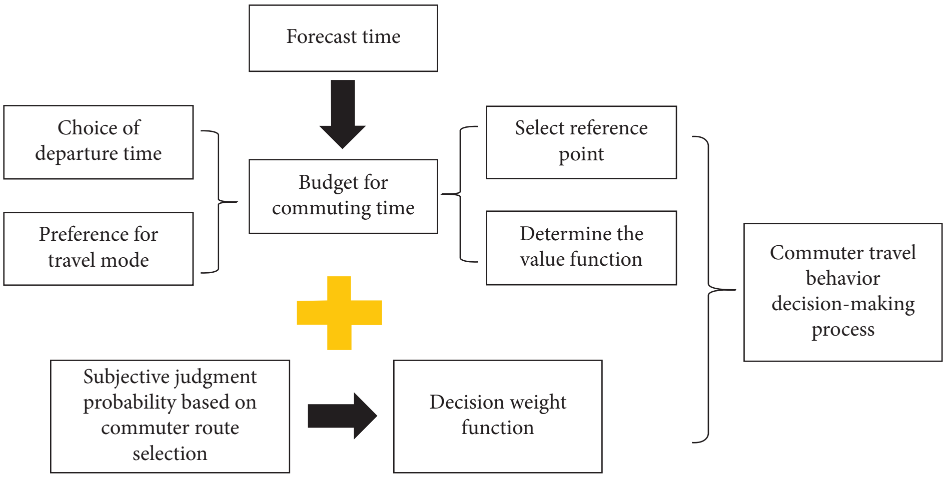

Figure 2: Commuter travel behavior decision-making process.

income families. On this basis, the regularity of the influence of different family and personal attributes on travelers was analyzed. Through a combination of online and offline questionnaire survey modes, this paper collected data from transportation stations, bus routes, and subway stations and commissioned the human resources department of enterprises after a period of 9 months. A total of 2,800 questionnaires were distributed, 2,578 were recovered, and invalid questionnaires and those with less than 2 minutes of cumulative answering time were excluded. A total of 2,332 questionnaires were effectively collected, with an effective recovery rate of 83.3%. The statistical results are shown in Table 1. The proportion of low-income commuters living alone is significantly higher than that of nonlow-income families, indicating that Xi'an metropolitan area has attracted more and more young people to work with the enhancement of its economic radiation driving ability, while nuclear families consisting of two and three members are still the main form of family formation. Comparing the number of vehicles owned by families with different income levels, it is found that the higher the family income level, the more the number of vehicles owned [17]. Among them, the proportion of low-income groups owning 2 or more bicycles/electric bicycles is slightly higher. After the development of the Times as a different mode of travel, motorcycles are more likely to be favored by young commuters, but their widespread ownership is still low. In terms of private cars, the impact of family income is most obvious, and the proportion of high-income families owning two or more cars is the highest compared with other families.

5. Simulation Analysis and Result Discussion

5.1. Scenario Assumptions and Results. Suppose that there are only four possible ways for commuters to choose to travel, and then, the assumptions are different according to the characteristics of each way [18].

Mode 1. Bus: there is a 70% probability of congestion, travel time is 60 min, there is a 30% probability of no congestion, travel time is 40 min, and the fare is 2 yuan

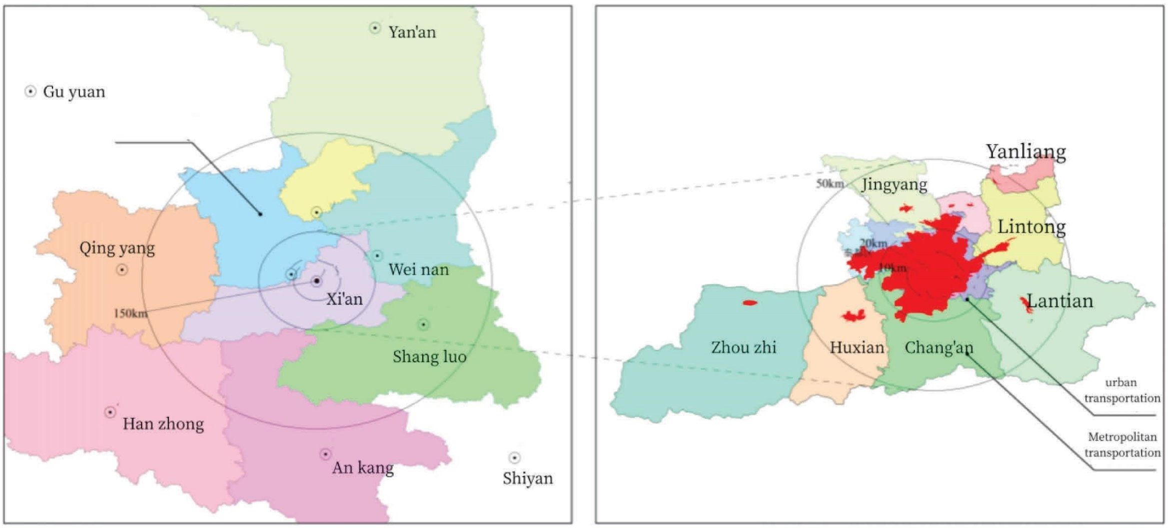

Figure 3: Transportation and spatial scale of Xi'an metropolitan area.

Table 1: Descriptive statistics of personal survey results for commuters.

Item	Characteristic	Low income ($N = 546$) (%)	Nonlow income ($N = 1{,}281$) (%)	High income ($N = 505$) (%)
Gender	Male	38.46	64.13	58.7
	Female	61.54	35.87	41.3
Age	Under 20 years old	42.31	6.62	0
	20–29 years old	11.54	27.41	8.7
	30–39 years old	7.69	34.18	18.48
Household size	Live alone	34.64	2.2	0
	2 people	26.92	18.45	9.78
	3 people	21.15	52.86	39.61
	More than 3 people	17.3	26.5	51.09
Car ownership rate	None	76.92	52.56	9.78
	One	19.23	36.6	42.39
	More than 2	3.85	10.84	47.82
Driving license ownership rate	None	65.38	60.76	17.39
	Yes	34.62	39.24	82.61

Mode 2. Subway: the total travel time is fixed at 30 min, and the fare is 4 yuan

Mode 3. Private car: the probability of congestion is 60%, the travel time is 45 min, there is a 40% probability of no congestion, the travel time is 35 min, and the cost is 20 yuan

Mode 4. New energy taxi: there is 60% probability of congestion, travel time is 40 min, there is 40% probability of no congestion, travel time is 30 min, and the cost is 40 yuan

By setting a scenario, considering the expected possibility of commuters' work time and departure time, the cumulative prospect value of the above method is calculated according to the constraint of the reserved time:

Scenario 1. commuters go to work at 9:00, start at 8:30, and need to arrive at work within 30 minutes

Scenario 2. the commuter's work time is 9:00, commuter's departure time is 8:20, and commuter needs to arrive at work within 40 minutes

Scenario 3. the commuter's work time is 9:00, commuter's departure time is 8:10, and commuter needs to arrive at work within 50 minutes

Scenario 4. commuters start work at 9:00, depart at 8:00, and need to arrive at work within 60 minutes

Tables 2–9 show the perceived costs and cumulative prospect values of traveler decision-making under four different scenarios calculated through the model.

By integrating the results of the above four scenarios, we can get the cumulative prospect value of commuters using travel costs as reference points under different travel constraints. Based on the specific data, the following conclusions are drawn: Under the premise of expected utility theory, subway becomes the optimal travel mode for commuters

Table 2: Expected travel costs for different transportation modes under scenario 1.

	Bus	Subway	Car	New energy taxi
Expected travel time	60 min, 70% 40 min, 30%	30 min	45 min, 60% 35 min, 40%	40 min, 60% 30 min, 40%
Perceived travel costs	88.6, 70% 35.7, 30%	55.47	123.82, 60% 59.24, 40%	104.2, 60% 48.5, 40%
Expected value of travel cost	66.32	55.47	97.231	87.36

Table 3: Expected travel costs for different transportation modes under scenario 2.

	Bus	Subway	Car	New energy taxi
Expected travel time	60 min, 70% 40 min, 30%	30 min	45 min, 60% 35 min, 40%	40 min, 60% 30 min, 40%
Perceived travel costs	68.94, 70% 50.31, 30%	32.7	84.43, 60% 69.085, 40%	78.4, 60% 35.6, 40%
Expected value of travel cost	70.28	32.7	73.216	67.77

Table 4: Expected travel costs for different transportation modes under scenario 3.

	Bus	Subway	Car	New energy taxi
Expected travel time	60 min, 70% 40 min, 30%	30 min	45 min, 60% 35 min, 40%	40 min, 60% 30 min, 40%
Perceived travel costs	58.81, 70% 47.65, 30%	48.3	79.423, 60% 68.514, 40%	67.247, 60% 38.588, 40%
Expected value of travel cost	53.63	48.3	84.656	60.6

Table 5: Expected travel costs for different transportation modes under scenario 4.

	Bus	Subway	Car	New energy taxi
Expected travel time	60 min, 70% 40 min, 30%	30 min	45 min, 60% 35 min, 40%	40 min, 60% 30 min, 40%
Perceived travel costs	62.08, 70% 50.21, 30%	50.8	82.646, 60% 70.508, 40%	64.8, 60% 40.2, 40%
Expected value of travel cost	55.7	50.8	88.432	62.1

Table 6: The cumulative foreground value of different traffic modes under scenario 1.

	Bus	Subway	Car	New energy taxi
Travel cost reference point	30.07	24.42	58.92	50.23
Travel cost function value	−81.56, 70% 0, 30%	−45.63	−63.43, 60% 0.76, 40%	−60.54, 60% 0.89, 40%
CPV	−36.54	−45.72	−34.88	−30.48

Table 7: The cumulative foreground value of different traffic modes under scenario 2.

	Bus	Subway	Car	New energy taxi
Travel cost reference point	32.56	28.4	78.3	56.2
Travel cost function value	−55.64, 70% −28.12, 30%	−2.656	−8.74, 60% 1.79, 40%	−60.23, 60% 1.06, 40%
CPV	−30.51	−25.078	−7.37	−26.3

because of its own convenience and punctuality. Under the framework of cumulative prospect theory, subway and bus are still the best choice for commuters as public transportation. It is worth noting that in the process of transportation policy, transformation to new energy vehicles, new energy taxis, due to their low energy prices and can drive in bus lanes, can alleviate the increase in travel costs caused by ground congestion to a certain extent [19].

Table 8: The cumulative foreground value of different traffic modes under scenario 3.

	Bus	Subway	Car	New energy taxi
Travel cost reference point	50.74	36.76	76.53	60.41
Travel cost function value	−33.2, 70% −26.5, 30%	−9.2	0.57, 60% 0.69, 40%	−27.8, 60% −24.3, 40%
CPV	−29.07	−20.34	−6.52	−23.65

Table 9: The cumulative foreground value of different traffic modes under scenario 4.

	Bus	Subway	Car	New energy taxi
Travel cost reference point	46.38	31.17	70.48	62.6
Travel cost function value	−36.89, 70% −20.05, 30%	−7.6	0.36, 60% 0.72, 40%	−30.4, 60% −21.9, 40%
CPV	−26.56	−19.5	−4.41	−24.81

However, due to the continuous growth of private cars in recent years, the area occupied by ground roads has increased significantly. Although private cars have certain advantages in acceptable commuting time, it is difficult to overcome the constraints of congestion probability and travel cost.

5.2. Analysis of Cumulative Prospect Value of Travel Time. Due to the analysis in Section 5.1, we find that private cars and new energy taxis have obvious similarities in travel costs. Therefore, in this part of the analysis, we mainly discuss taxi, subway, and bus travel modes. MATLAB is used to nonlinear fit the travel time and cumulative foreground value, and the fitting results only consider the travel time. Suppose the time reference points are 30 minutes, 35 minutes, 40 minutes, 45 minutes, and 60 minutes. The specific fitting results are shown in Figure 4. As the values of the time reference points increase successively, the prospects of these three modes of transportation show an upward trend. The prospect values of subway and taxi are relatively similar and higher than that of bus. The travel time reference point is between 20 and 35 minutes, and the prospect value of taxi is slightly higher than that of subway. However, when the reference point is greater than 35–60 minutes, the foreground value of the subway is higher than that of the taxi. When the reference point is 36 min, there is an intersection between the cumulative foreground values of the two modes of transportation. Combining the fitting curves of the two travel modes, it can be concluded that when the travel time reference point is 37–39 minutes, the cumulative prospect values of the two travel modes are equal, and the probabilities of commuters choosing subway and taxi are similar. Commuters can choose the right means of transportation according to their travel preferences. Therefore, when commuters have high travel time requirements and no travel costs, they can choose to use taxis as commuting tools.

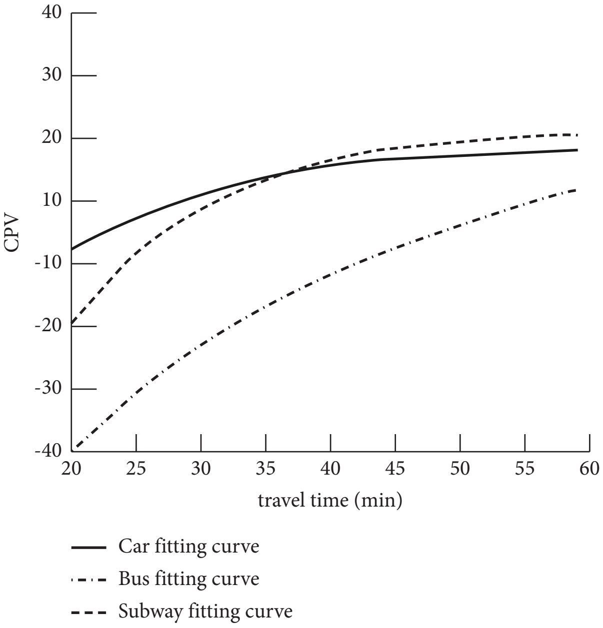

Figure 4: Cumulative prospect value of travel time.

5.3. Analysis of Cumulative Prospect Value of Travel Expenses. Based on the cumulative prospect theory, the cumulative prospect value of each travel mode under different reference points can be calculated. Using the principle of least square method, the travel cost and cumulative prospect value are nonlinear fitted by fitting software. The fitting results are shown in Figure 5. Due to the small difference in bus and subway fares, and the much higher cost of taxi travel than bus and subway travel, the cumulative prospect value of bus and subway is much greater than that of taxi. It can be seen from the fitting curves of the three travel modes that the cumulative foreground values of bus and subway are relatively close at different travel cost reference points. Since bus fares are lower than subway fares, the cumulative prospect value of subway is close but always lower than that of bus. Commuters can reduce travel costs by using buses regardless of travel time. It can be seen from the slope of the fitted curve that the slope of the bus and subway curve is relatively small, while the slope of the taxi curve is larger, indicating that the cumulative prospect value of the taxi increases significantly with the increase of the reference point, and it is closer and closer to people's psychological expectation.

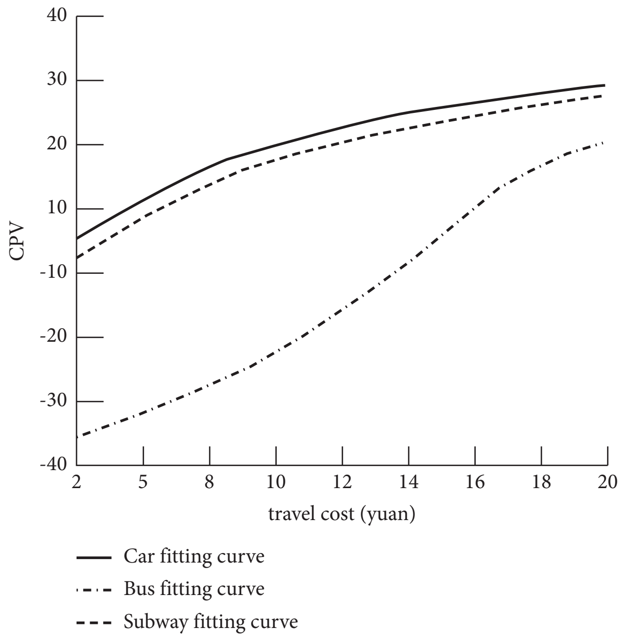

Figure 5: Cumulative prospect value of travel cost.

6. Conclusion

Commuters will make rational judgments according to the actual travel time and travel cost. On the premise that they reserve enough time and ensure that they will not be late for work, commuters will prefer to choose the more secure means of transportation with low congestion probability when facing benefits. The different hypothetical time reference points are 30 minutes, 35 minutes, 40 minutes, 45 minutes, and 60 minutes. As the value of the time reference point increases successively, the prospects of these modes of transportation show an upward trend. The prospect values of subway and taxi are relatively similar and higher than that of bus [20].

This paper constructs a travel behavior selection model for office workers based on the cumulative prospect theory, introduces the time value of commuter travel into the generalized travel cost function, uses the weight function and the improved generalized travel cost function as the basis of the transportation mode selection model, defines the reference point of generalized travel cost in the model, and selects the prospect with the largest cumulative prospect value as the optimal decision of travelers. Based on the "expected utility maximization theory" and the "cumulative prospect theory," the commuter is simulated under four different travel scenarios to study the optimal mode selection behavior. The results show that under the framework of expected utility theory, the travel mode choice behavior of commuters is not affected by travel scenarios, and the cumulative prospect theory is more suitable for the study of travel mode choice behavior. Constructing a transportation mode selection model with the value of commuting travel time as the core variable can help commuters choose reasonable transportation modes and provide a basis for the government and relevant departments to formulate traffic management plans and implement policies to alleviate traffic congestion [21].

The commuter travel behavior model based on the cumulative prospect theory established in this article mainly focuses on conventional buses, subways, private cars, and new energy taxis and sets up four travel scenarios to explore the mechanism of commuters choosing the optimal transportation mode. In the subsequent research, we can further enrich and expand other transportation tools, increase scene settings, and use big data to integrate commuting data to improve the research and application of cumulative prospect theory in transportation travel.

Data Availability

The raw data supporting the conclusions of this paper will be made available by the authors, without undue reservation.

Ethical Approval

This study did not involve human or animal subjects; thus, no ethical approval was required. The survey questionnaire designed by this research institute does not involve the privacy of the respondents during the distribution process, and it is explained to the respondents that the questionnaire data is anonymous, and the research results are not applied to the subjects, so ethical approval is not required. The research plan complies with the guidelines formulated by the journal.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Dai Xin (first author) conceptualized the study, developed the methodology, provided software, investigated the study, performed formal analysis, and wrote the original draft. Tianshan Ma visualized the study and reviewed and edited the study.

References

[1] P. O. Muller, *Transportation and Urban Form-Stages in the Spatial Evolution of the American metropolis*, Guilford Publications, New York, NY, USA, 2004.

[2] P. Waddell, G. F. Ulfarsson, J. P. Franklin, and J. Lobb, "Incorporating land use in metropolitan transportation planning," *Transportation Research Part A: Policy and Practice*, vol. 41, no. 5, pp. 382–410, 2007.

[3] R. B. Thapa and Y. Murayama, "Urban growth modeling of Kathmandu metropolitan region, Nepal," *Computers, Environment and Urban Systems*, vol. 35, no. 1, pp. 25–34, 2011.

[4] M. J. Jun, "The effects of polycentric evolution on commute times in a polycentric compact city: a case of the Seoul Metropolitan Area," *Cities*, vol. 98, Article ID 102587, 2020.

[5] F. S. Koppelman and C. H. Wen, "Alternative nested logit models: structure, properties and estimation," *Transportation Research Part B: Methodological*, vol. 32, no. 5, pp. 289–298, 1998.

[6] Y. Li and S. Lu, “Study on the optimization of urban passenger traffic structure based on multi-objective linear programming—a case study of Beijing,” *Environmental Science and Pollution Research*, vol. 28, no. 8, pp. 10192–10206, 2021.

[7] H. Dezani, R. D. S. Bassi, N. Marranghello, L. Gomes, F. Damiani, and I. Nunes da Silva, “Optimizing urban traffic flow using Genetic Algorithm with Petri net analysis as fitness function,” *Neurocomputing*, vol. 124, pp. 162–167, 2014.

[8] Q. Wang and H. Sun, “Traffic structure optimization in historic districts based on green transportation and sustainable development concept,” *Advances in Civil Engineering*, vol. 2019, Article ID 9196263, 18 pages, 2019.

[9] P. Næss, “Compact urban development in Norway: spatial changes, underlying policies and travel impacts,” *Advances in transport policy and planning*, vol. 9, pp. 95–133, 2022.

[10] Y. Deng and P. Zhao, “The impact of new metro on travel behavior: panel analysis using mobile phone data,” *Transportation Research Part A: Policy and Practice*, vol. 162, pp. 46–57, 2022.

[11] S. Rasouli and H. Timmermans, “Applications of theories and models of choice and decision-making under conditions of uncertainty in travel behavior research,” *Travel Behaviour and Society*, vol. 1, no. 3, pp. 79–90, 2014.

[12] X. Chang, J. Wu, H. Liu, X. Yan, H. Sun, and Y. Qu, “Travel mode choice: a data fusion model using machine learning methods and evidence from travel diary survey data,” *Transportmetrica: Transportation Science*, vol. 15, no. 2, pp. 1587–1612, 2019.

[13] K. Gao, L. Sun, Y. Yang, F. Meng, and X. Qu, “Cumulative prospect theory coupled with multi-attribute decision making for modeling travel behavior,” *Transportation Research Part A: Policy and Practice*, vol. 148, pp. 1–21, 2021.

[14] D. A. Hensher, Z. Li, and C. Ho, “The role of source preference and subjective probability in valuing expected travel time savings,” *Travel Behaviour and Society*, vol. 2, no. 1, pp. 42–54, 2015.

[15] S. An, X. Hu, and J. Wang, “A cumulative prospect theory approach to car owner mode choice behaviour prediction,” *Transport*, vol. 29, no. 4, pp. 386–394, 2014.

[16] Y. Li, L. Yang, H. Shen, and Z. Wu, “Modeling intra-destination travel behavior of tourists through spatio-temporal analysis,” *Journal of Destination Marketing & Management*, vol. 11, pp. 260–269, 2019.

[17] G. D. Jong, J. Fox, A. Daly, M. Pieters, and R. Smit, “Comparison of car ownership models,” *Transport Reviews*, vol. 24, no. 4, pp. 379–408, 2004.

[18] X. Dai, T. Ma, and E. Zhou, “New energy commuting optimization under low-carbon orientation: a case study of xi’an metropolitan area,” *Energies*, vol. 16, no. 23, p. 7916, 2023.

[19] D. Pojani and D. Stead, “Sustainable urban transport in the developing world: beyond megacities,” *Sustainability*, vol. 7, no. 6, pp. 7784–7805, 2015.

[20] T. Wu, Q. Shen, M. Xu, T. Peng, and X. Ou, “Development and application of an energy use and CO2 emissions reduction evaluation model for China’s online car hailing services,” *Energy*, vol. 154, pp. 298–307, 2018.

[21] S. Ma, Z. Yu, and C. Liu, “Nested logit joint model of travel mode and travel time choice for urban commuting Trips in Xi’an, China,” *Journal of Urban Planning and Development*, vol. 146, no. 2, Article ID 04020020, 2020.