A study of Commuters' and non-Commuters' Travel Mode Choice Behavior Based on the Value of Time

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Abstract. The study of the value of travel time is of great importance in transportation projects. Studying the value of travel time for commuters and non-commuters can help optimize transportation policy and infrastructure planning, especially in reducing congestion and improving efficiency. Understanding the different views of different groups on travel time can help to better meet the needs of different groups and improve their sense of well-being; at the same time, it can be used to plan and optimize transportation modes according to the different behavioral patterns of travel mode choices adopted by different groups with different values of time, and promote the balance between supply and demand. Promote more effective social resource allocation. This paper adopts orthogonal experimental design method to design the SP survey, and establishes a multinomial logit model for random utility maximization based on the travel data of commuters and non-commuters obtained by the SP survey method. Calculating the value of time for residents with different travel purposes (commuter and non-commuter) choosing different travel modes, it is concluded that the value of time for commuters is generally higher than that for non-commuters.

Keywords: transportation engineering; value of travel time; orthogonal experiments; multinomial logit models

1 INTRODUCTION

The value of time is a key indicator in transportation research for assessing economic efficiency and optimizing transportation policies, influencing the behavioral choices of travelers and the effectiveness of policy formulation.

The value of travel time determines the generalized cost of different groups of people under different travel purposes and mode choices in the macro model, which in turn affects the results of transportation allocation[2]. According to the previous literature[1], the calculation methods of time value are broadly divided into two: one is the direct method, which is to estimate the time value through market behavior or survey data. This method usually uses behavioral data of travelers, such as time cost and willingness to pay, to infer the time value. For example, by observing people's choices and payment behaviors under different modes of travel, their actual assessment of time can be

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estimated; the other is the indirect method, where the indirect method calculates the value of time by building an economic model. This method is often used to assess the impacts of policies, programs, or systems. It is usually based on theoretical modeling or statistical analysis that uses economic principles to estimate the impact of different time costs on economic benefits. For example, the impact of time value can be indirectly estimated by building a cost-benefit analysis model or a transportation demand model[1]. At this stage in China, the value of time is mainly studied through the non-collective model[4]. Xiao Mei[3]and others used a multinomial Logit model, the purpose of travel and whether to transfer as the main variables for waiting time value research, refining the types of travel time value; Yu Zhang[7]used the theoretical basis of the non-collective model to optimize the travel value calculation model, and used multinomial logit to calculate the travel time value of various groups of people in Chengdu; Maria Börjesson[6]synthesizes the results and insights from Swedish time value studies, focusing on elements related to transportation assessment and understanding travel behavior, summarizes recent advances in econometrics, and shows how these advances can lead to a better understanding and identification of the value of time distributions; Manuel Ojeda Cabral[5]investigates for the first time passengers' perceptions of and preferences for recovery time use. The results of a large experimental study of stated preferences are summarized and passenger valuations of recovery time, both relative to in-vehicle time and tardiness, are provided, which can be used for economic evaluation purposes; Using the Europe-wide transportation dataset collected in 2019, Ghadir Pourhashem[8]incorporated the subjective factors proposed by the H2020 MoTiV project into the travel time value assessment using a multinomial logit model to study and analyze the impact of travel characteristics, emotions, socio-demographic traits, experiential factors, travel activities, and weather on the travelers' perceptions of travel time value; Basil Schmid[9]estimates the value of leisure (VOL), the value of travel time saved (VTTS) and the resulting value of time allocated to travel (VTAT) for workers in the canton of Zurich, Switzerland, and the results of the study suggest that travel comfort is so important that more attention should be paid to investing in travel quality and developing relevant policies; Haotian Zhong[10]applied a hybrid logit model to quantify the change in the value of travel time in self-driving cars, and investigated the potential impact of self-driving cars on the value of travel time (VOTT) for commuters.

In this paper, we obtain data on travelers' habits and willingness to pay through the SP survey method, take whether travelers use commuting as the purpose of travel as the starting point, study the impact of the purpose of travel and travelers' choice of transportation mode for this purpose on the value of travel time, and establish a multinomial Logit model-based time value estimation method, which can be used to compute the value of time for residents with different purposes of travel (commuting vs. non-commuting) who choose different modes of travel Time Value.

2 A GROUNDED THEORY OF THE VALUE OF TRAVEL TIME

2.1 The Meaning of Travel Time Value in Economics

In economics, the value of travel time refers to the economic and opportunity costs that individuals or groups experience when making travel decisions. It encompasses not just the time spent directly in transit, but also considers the consequential loss of time for other activities and the psychological stress incurred. This concept holds significant relevance in transportation economics and urban planning. It is crucial for evaluating transportation policies, setting public transportation fares, implementing congestion pricing, and planning transportation infrastructure. The goal is to optimize transportation system efficiency and enhance the quality of life for residents.

2.2 Characteristics of the Value of Travel Time and Factors Affecting it

The value of travel time in transportation economics arises from an individual's trade-off between time and cost, quantified primarily by the marginal rate of time substitution. This concept is categorized into two types: resource time value, crucial for evaluating transportation investments, and behavioral time value, which focuses on urban congestion management and travel behavior analysis. While resource time value finds more extensive application in China, behavioral time value remains relatively underexplored, necessitating further research and practical implementation.

The value of travel time encompasses not only the direct time spent in travel but also the opportunity cost of time lost from potential alternative activities. This dual consideration underscores its economic significance. When individuals decide between saving time and incurring additional costs, a higher marginal rate of substitution of time indicates a greater willingness to pay to save time. The perceived value of travel time varies significantly among individuals based on factors such as income, lifestyle, occupational requirements, and personal preferences for time allocation. Furthermore, psychological stress and discomfort associated with long journeys or traffic congestion are pivotal factors influencing the value of travel time.

3 MULTINOMIAL LOGIT MODEL

Currently, the production method, the wage method, the cost method and the non-aggregate model are the main methods for calculating the value of travel time. The non-aggregate model pays special attention to studying the influence of individual subjective factors on the value of travel time, so it is more applicable and relatively easy to calculate in practical applications. In this paper, we will establish a non-aggregate model based on SP survey data to reveal the specific value of time felt by travelers under different travel purposes.

Multinomial logit model is usually regarded as a kind of non-aggregate model[4] Non-aggregate modeling is an analytical approach that focuses on inter-individual differences and their different preferences for decision-making problems. These models are usually based on the subjective choices and preferences of individuals and do not rely on pooled (aggregated) statistics. A multinomial logit model is a common type of non-aggregate model that is used to analyze the probability distribution between multiple discrete choices, such as a consumer's purchase choice or a traveler's travel choice.

Multinomial logit modeling is suitable for exploring differences in preferences between different choices and is able to quantify the relative degree of preference for each choice. It is often used in transportation economics to analyze travelers' choices between different modes of travel (e.g., car, public transportation, walking, etc.), so as to understand the travel decision-making process of an individual under the influence of time, cost, and other factors.

Therefore, the multinomial logit model belongs to the category of non-collective models because it takes into account the subjective choices and preferences of individuals and does not rely on the statistical analysis of collected data.

The multinomial Logit model is based on the theory of random utility maximization[4], there exists a set of travel modes $A=\{A_1,A_2,\ldots\ldots,A_n\}$,, for traveler n, the utility of choosing one of the options j is U_{jn},then the condition for this traveler to choose option i from An is the following equation:

$$U_{in} > U_{jn}, j \neq i, j \in A_n \tag{1}$$

Random utility theory considers utility as a random variable and therefore divides the utility function U_{in} into fixed terms V_{in} and ε_{in} and assumes that they are linear.

$$U_{in} = V_{in} + \varepsilon_{in} \tag{2}$$

The utility function fixed term V_{in} represents the utility of the observable element vector X_{in} and is usually expressed as the following linear relationship:

$$V_{in} = \sum_{k=1}^{k} \theta_k X_{ink} \tag{3}$$

Where X_{ink} is the value of the kth characteristic variable of traveler n's choice of option i, and θ_k is the coefficient to be determined.

The zero utility function random term ε_{in} obeys a bivariate exponential distribution with parameters (0, 1), then ε is 1 and the final choice probability is:

$$P_{iq} = \frac{exp[V_{in}]}{\sum_{j\in A_n} \exp\,[V_{jn}]} = \frac{e\sum_{k=1}^{k}\theta_k X_{ink}}{\sum_{j\in A_n} e\sum_{k=1}^{k}\theta_k X_{ink}} \tag{4}$$

In particular, the characteristic variable X_{ink} represents the characteristic variables of the choice option, including the choice option intrinsic dummy variable, the choice option intrinsic variable, and the choice option public variable. Generally there is no inherent variable of choice scheme for all kinds of transportation modes, and the characteristic variables of choice scheme are the public variables of choice scheme, time t and cost and f, and k-1 inherent dummy elements (the kth inherent dummy element, ASC_k, is always 0). Based on this theory, the modeling characteristic variables are shown in Table 1.

Referring to foreign research results, the important factors affecting travelers' choice of different modes are cost and time, so the expression of utility V is:

$$V_i = a_i + b_i P_i + c_i T_i \tag{5}$$

In Equation (5) a_i, b_i, c_i are the coefficients to be determined; P_i, T_i are the cost and time consumed by the traveler's chosen i-th mode or route; n is the number of available modes and routes. The formula for the value of travel time VOT is shown below:

$$VOT = \frac{\partial v_i / \partial t_i}{\partial v_i / \partial f_i} = \frac{\partial t_i}{\partial f_i} \tag{6}$$

The solution of the multinomial Logit model includes the establishment of the great likelihood function, the calculation of the optimal estimates, and other specific steps in the relevant literature[4].

Table 1. Characteristic variables table.

Options	**Utility**	**Choice Program Inherently Dumb Dollars**				**Selection of program public variables**	
		X_{in1}	X_{in2}	⋯	X_{ink}	Time (min) （X_{in4}）	Costs (￥) （X_{in5}）
Mode 1	V_{1n}	1	0	⋯	0	X_{1n4}	X_{1n5}
Mode 2	V_{2n}	0	1	⋯	0	V_{2n4}	V_{2n5}
⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯
Mode k	V_{kn}	0	0	⋯	1	X_{kn4}	X_{kn5}
Unknown parameter		ASC_1	ASC2	⋯	ASC_3	θ_f	θ_t

4 DATA ACQUISITION AND PROCESSING

4.1 Questionnaire Design

The accuracy as well as reliability of the survey data is conducive to the modeling of the value of travel time, which is largely dependent on the design of the SP contextual mix. It is generally desired to get enough information from the respondents, but it is worth noting that too many survey questions should not be designed to avoid boredom in the process of filling out the questionnaire by the respondents, which will lead to a decrease in the accuracy of the acquired data. In order to achieve this purpose, this paper adopts orthogonal design for the design of the questionnaire, which can reduce the number of scenarios and facilitate the investigation.

The orthogonal experimental design is based on the principles of rationality, reliability, constraints and simplicity, and the experimental points with the characteristics of "uniformly dispersed and neatly comparable" are selected from all the experimental points. Orthogonal experimental design will be each factor of each level and another factor of each level to build a scenario. SPSS, that is, statistical products and services solutions, is one of the world's most famous statistical analysis software, the use of SPSS software for the design of orthogonal experiments, can be simplified from the complexity of the combination of different factors into a specification of the table, can be reasonably arranged for the test of the relevant factors and levels, generally speaking, the usual orthogonal experimental design. Generally speaking, orthogonal experiments need it as a basic tool to participate in the design.

For example, in Shanyang District of Jiaozuo City, there are about seven types of existing travel modes: walking, bicycles, shared bicycles, shared electric vehicles, public transportation, cabs, and private cars. This design chooses five travel modes to build the scenario: shared bicycle, shared electric vehicle, public transportation, cab, and private car due to the characteristics of walking and bicycling, such as no cost expenditure. The time and cost of each travel mode in each scenario are determined based on the average travel time consumption and distance of the travel survey of residents in Shanyang District as shown in Table 2.

Table 2. Time and cost breakdown of the various modalities.

Mode of travel	Time (min)			Cost (¥)		
Bus	30	60	90	1	1.5	2
Cabs	15	30	45	33	69	105
Private car	18	36	54	18	37	56
Shared Electric Vehicles	45	90	135	3	4.5	7.5
Shared bicycle	60	120	180	1	2	3

From Table 2, it can be seen that the residents of Shanyang District travel SP survey has a total of 10 factors: bus travel time, cab travel time, private car travel time, shared bicycle travel time, shared electric vehicle travel time, bus travel cost, cab travel cost, private car travel cost, shared electric vehicle travel cost, and shared bicycle travel cost, and each factor has three levels, and according to the orthogonal design, 10 factors 3 levels can design 27 scenarios.

To fully consider the operability of the survey, the respondents should be difficult to accept the 27 scenarios of the question to fill in under normal circumstances, so the questionnaire will be divided into three before the survey, and the respondents only need to fill in nine scenarios.

4.2 Statistics and Analysis of Data

The content of the questionnaire is divided into three main parts:

The first part of the respondent's socio-economic attributes; the second part of the display preference survey, which mainly includes the purpose frequency reasons, etc.; and the third part of the stated preference survey, which is combined into scenarios.

The questionnaire to determine the sample size formula is shown below:

$$n = \frac{Z^2 p(1-p)}{e^2} \tag{7}$$

Where: n is the sample size, Z is the standard error associated with the chosen confidence interval, p is the variability of the overall estimate, and e is the acceptable error.

When the overall parameter p is unknown, the following methods of estimation can be applied: estimation of the parameter p based on past data or survey data; if past data and survey data are not available, then p=0.5 should be chosen. this is because when p=0.5, the value of p(1-p) is maximized, thus avoiding underestimation of the sample size, and it is a prudent estimate.

It is expected that estimating the sample size with a 95% confidence interval and a margin of error not exceeding 5% would result in a sample size of approximately 384.

$$n = \frac{Z^2 p(1-p)}{e^2} = \frac{1.96^2 0.5(1-0.5)}{0.05^2} \approx 384 \tag{8}$$

A total of 422 questionnaires were collected in this survey, and when the results of the choices made by the travelers do not match with their personal attributes, they are invalid questionnaires, and the valid questionnaires are 405 after elimination.

The statistics of the proportion of basic information of this survey population are shown in Figure 1 below:

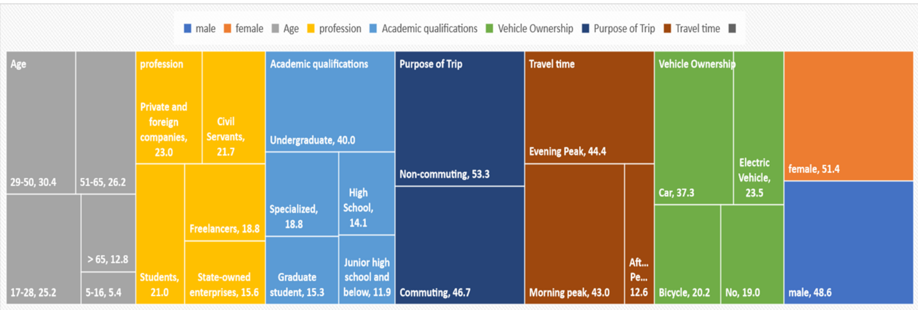

Fig. 1. Statistical chart of the proportion of traveling situations.

This survey showed that 48.6% of the participants were male and 51.4% were female, indicating a relatively balanced gender ratio. The age distribution was mainly concentrated in the 29-50 age group (30.4%), followed by the 17-28 age group (25.2%), indicating that the survey respondents were mainly an adult group. In terms of occupation, private and foreign enterprise companies (23.0%) and civil servants (21.7%) accounted for a relatively high percentage, reflecting the diversity of respondents' occupations. In addition, bachelor's degree accounted for 40.0% of the respondents, which is the most dominant educational group,Regarding travel habits, more than one-third owned a car (37.3%) and most traveled for non-commuting purposes (53.3%).

In summary, the survey results demonstrate the distribution of respondents in terms of gender, age, occupation, education and travel purpose, highlighting the characteristics and preferences of various groups in society.

5 TRAVEL TIME VALUE CACLULATION AND ANALYSIS

On the basis of the data obtained from the above SP survey, the parameters were calibrated using maximum likelihood estimation, and the value of time was calculated by applying multivariate Logit model on Python 3.8 software (Table 3). Among them, θ_t and θ_f represent the estimated parameters of time and cost respectively, and VOT is the time value. And the following conclusions were drawn through the comparison of time values for the same travel mode but different travel purposes (Figure 2).

Table 3. Value of time for different modes of travel for commuters and non-commuters.

Category	θ_t	θ_f	VOT/ (¥·h^{-1})
Public Transportation Commuting	-0.0541	-0.2342	20.2
Cab Commuting	-0．0649	-0.0743	43.3
Private Car Commuting	-0.0294	-0.0556	35.4
Shared Electric Vehicle Commuting	-0.0168	-0.0720	8.2
Shared Bicycle Commuting	-0.0169	-0.0965	11.1
Public Transportation-Non-Commuting	-0.0872	-0.5432	17.9
Cab - Non-Commuting	-0.0645	-0.0741	40.6
Private Car-Non Commuter	-0.0292	-0.0557	36.6
Shared Electric Vehicle-Non Commuting	-0.0169	-0.0722	8.1
Shared Bicycle - Non-Commuting	-0.0170	-0.0966	10.3

First, as can be seen from the data presented in Table 3, all the coefficients for time and cost are negative, which indicates that either an increase in travel time or cost leads to a decrease in the probability of the traveler choosing this mode of travel in line with reality. Second, the value of non-commuting is greater than commuting only for private car travelers in Figure 2 because private car travelers usually want to use their time as efficiently as possible during their commute in order to enjoy more freedom and leisure during their non-commuting time. In addition, private automobiles provide greater commuting efficiency and predictability, reducing time cost and economic cost considerations. Other data, on the other hand, amply demonstrate that the value of time for travelers whose trip purpose is commuting is generally greater than that of travelers whose trip purpose is something else, and that commuters typically face the time cost of traveling to and from work on a daily basis. As a result, they may be more concerned about the importance of saving time and be willing to pay a higher fee or choose a more efficient mode of travel for that purpose.

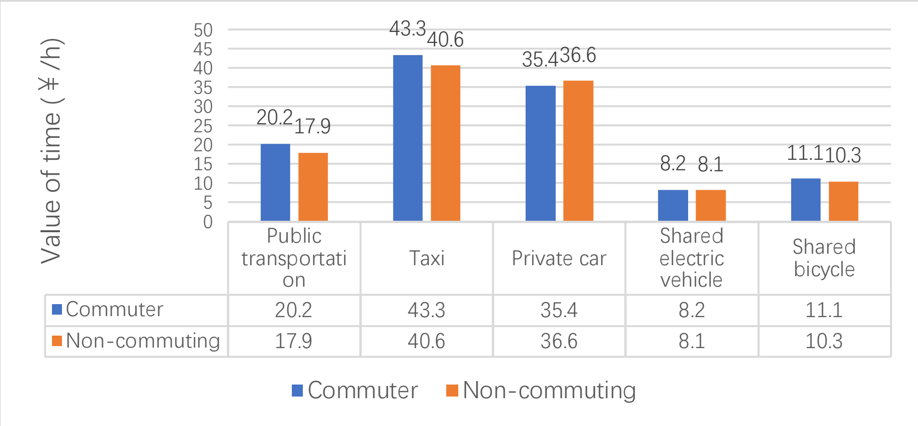

Fig. 2. Comparison of the value of travel time.

According to the choice probability data plot in Figure 3, the value of travel time versus the predicted choice probability shows several key trends. First, the high choice probability of public transportation (35.3%) reflects the fact that most people prefer affordability as a primary consideration, even if it may mean an increase in time cost. In contrast, private cars (15.3%) and shared electric vehicles (19.8%) have a slightly lower probability of choice, but show the importance individuals place on flexibility and convenience of travel, especially in terms of scheduling predictability. Second, the probability of choice for shared bikes (18%) shows that a portion of the population is concerned with environmental protection and sustainability, although this choice usually implies a certain compromise in terms of time efficiency and convenience. This represents the fact that since the time cost of commuting directly affects their productivity at work or school, commuters are likely to place a greater emphasis on time savings and be willing to make sacrifices in order to minimize their commute time.

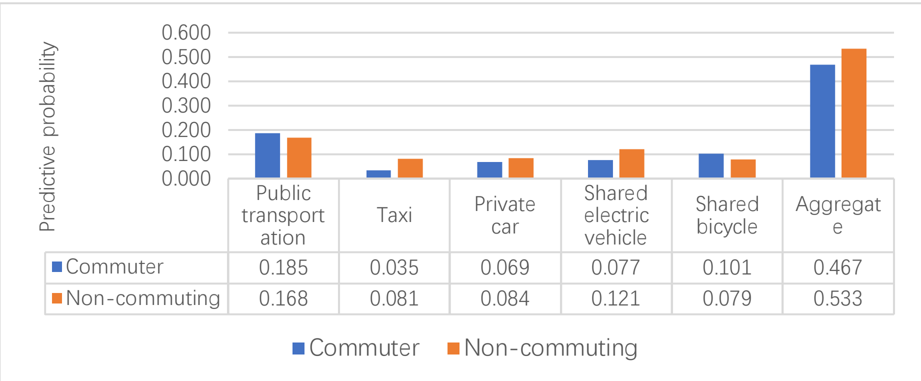

Fig. 3. Predictive selection probability map.

6 CONCLUSION

Estimating the value of travel time involves a number of aspects and factors. First, a breakdown of the value of time under different choice modes and travel purposes helps us to understand more accurately how different travelers perceive and value time. For example, commuters may be more inclined to choose short-distance transportation modes to improve their productivity and quality of life, while non-commuters may be more concerned about controlling travel costs and have a more elastic demand for time. Second, this segmentation can guide the individualized formulation and optimization of transportation policies. By accurately analyzing the value of time for different groups, policy makers can optimize the design of transportation networks and adjust transportation services and facilities to maximize socio-economic benefits and satisfy various travel needs. This refined approach helps to improve the overall efficiency and sustainability of the transportation system while promoting urban development and the quality of life of residents.

In this paper, taking Shanyang District of Jiaozuo City as an example, we design and distribute questionnaires through the orthogonal design method to obtain data on residents' travel behavioral habits and travel intentions, and then construct a multinomial logit model to calculate the value of time spent by residents choosing different travel modes for different travel purposes (commuters and non-commuters). The results of the study show that commuters value saving time more than non-commuters because commuting time directly affects their work or study efficiency. They are willing to make sacrifices in order to reduce their commute time. In contrast, non-commuters may be more focused on controlling travel costs and the need to save time is less urgent than commuters. In addition, commuters and non-commuters may have different income levels and economic status, which may also affect their perception of the value of time. With more accurate time-value analysis by the relevant authorities, policy makers can personalize and optimize transportation networks and services to meet the travel needs of different groups. For example, for the characteristics of commuters who value time, priority can be given to the development of efficient public transportation systems or the provision of transportation subsidy policies. Further research on the specific impacts of different transportation modes on the value of time can help refine existing models and strategies. For example, combining emerging intelligent transportation systems and data analytics technologies to more accurately predict and respond to residents' travel demand and improve the overall efficiency of the transportation system and user experience.

The article takes Shanyang District in Jiaozuo City as an example for the study, but it does not cover data from other regions or cities, and this geographical limitation may limit the generalizability and replication of the findings, and it may also result in the conclusions of the study not comprehensively reflecting the real situation of different regions and groups.

The value of a traveler's time depends not only on the purpose of the trip and the mode of transportation chosen, and subsequent studies could expand the scope of the survey to collect sufficient data to further refine the impact of different modes of transportation travel on the value of time.

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