Combination model of urban tourism transportation based on nested logit model

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**Abstract**

The traditional combination model based on multinomial logit is incapable of reflecting the nested structure of urban tourism destinations. Therefore, this paper established a variational inequality model of the combination of tourism demand distribution and transportation assignment based on nested logit. Through the first-order optimization conditions, it proved that the volume of travel distribution and transport assignment could meet the combination equilibrium conditions. Based on the MSA algorithm, it designed the solution algorithm of the model and verified the feasibility of the model and algorithm in a simplified tourism passenger transport network in Huangshan City. The calculation results show that the variational inequality model proposed in this paper can obtain the volume of travel distribution and transportation assignment at the same time, meanwhile compared with the multinomial logit, the nested logit structure fully considers the attraction measure of hotel and scenic spots, which is more in line with the choice behavior of tourists when choosing transportation route. In addition, the time value type of tourists has a great impact on the comprehensive tourism impedance which means that in the practical application, it is necessary to determine the time value type of tourists in each transportation routine reasonably.

**1. Introduction**

Driven by the rapid development of high-speed rail and aviation as well as the policy of all-for-one tourism, the external transportation of tourist destination cities has developed vigorously, while the development of transportation network for tourist flows within the city lags behind relatively, which seriously affects the travel experience of tourists and the establishment of demonstration area for all-for-one tourism in the city. In the developed external transportation network environment, the urban transportation network that can realize seamless connection, integrate with transportation and tourism, and operate efficiently highlights its importance.

Researchers have been trying to explain the basic laws and characteristics of tourists’ spatiotemporal behaviour, and have formed corresponding theoretical results. The study on temporal distribution characteristics of tourism flows mainly focuses on the statistical analysis and prediction of tourism flows. Kim and Moosa (2005) took direct and indirect methods to predict the tourism flows in Australia, making comparison and analysis of the advantages and disadvantages of the two methods. Zhu et al. (2018) proposed the copula-based approach combined with econometric models is for tourism demand analysis that can be used to predict tourist arrivals. Petrevska (2015) underlined the importance of identifying seasonality effects over tourism development by calculating some commonly applied indicators for measuring tourism seasonality, like Gini coefficient, Seasonality Indicator and Coefficient of Variation. The research on spatial structure characteristics of tourism flows mainly focuses on spatial agglomeration and diffusion as well as spatial behavior pattern and spatial network structure characteristics. Qin et al. (2019) explored the spatial characteristics of China’s inbound tourist flow, the spatial patterns of tourist movement, and the tourist destination cities group based on data mining techniques, including the Markov chain, a frequent-pattern-mining algorithm, and a community detection algorithm. Sugimoto et al. (2019) examined the relationship between visitor mobility and urban spatial structures through an exploratory analysis of visitors’ movements and characteristics, which were collected from surveys with global positional system (GPS) tracking technologies and questionnaires. Pavlovich (2002)
examined the process of tourism destination evolution and transformation and used network theory to express these dynamics, and it emphasized structural features of architectural density and centrality. Seok and Nam (2022) explored how the structure of international tourism has changed longitudinally using a social network analysis. In general, great achievements have been accumulated during the research on tourism flows, however, some problems still exist as follows: ① For the lack of panel data and the limitations of survey means, the research results on tourism flows are mainly focused on the large and medium scale among countries and provinces, and there are few studies on the micro scale among cities and scenic spots. ② There are many studies on the distribution of tourism flow in different space and time, but relatively fewer researches on the structure of tourism flow network as well as its causes and predictions. The research on the prediction of tourism transportation mode is mainly to divide the tourism transportation mode under the premise of given OD distribution, taking traditional survey statistics data or microblog check-in data under the Internet background. Qi et al. (2020) explored the relationship between destination means of transportation and travel chain based on nested Logit, and takes two nested structures to analyze the decision-making process of travelers. Malik and Kim (2019) designed objective function of tourist routine optimization by taking neural network and particle swarm optimization algorithm base on five route parameters: distance, road congestion, weather conditions, route popularity and user preference. Through smart travel card data, Gutiérrez et al. (2020) analyzed tourists use condition of urban public transport. Trinh and Le (2017) took binary Logit model to study tourists mode choice behavior and believed that the main factors affecting tourists choice of transportation mode on travel route include socioeconomic factors (like family income and age of interviewees) and travel characteristics (like total travel time and travel budget). Ghader et al. (2021) introduce a multi-dimensional continuous activity scheduling choice modeling framework. It focuses on modeling the joint choice of arrival to an activity and departure from the activity. Each of the choices is modeled in continuous time using based on the continuous cross-nested logit model. Shanmugam and Ramasamy (2021) created a model choice from specific urban communities (Coimbatore, Erode, Salem and Trichy) to Chennai with the nested logit model. Bastariano et al. (2019) attempt to measure and compare the relationship between tour type and model choice using three different modelling approaches: Multinomial Logit (MNL), Nested Logit (NL) and Cross-Nested Logit (CNL).

It is found that most studies tend to estimate the proportion of tourists choosing a certain mode of transportation with the help of Logit stochastic utility model with the help of origin-destination distribution. However, they did not consider the influence relationship between transportation mode choice and OD distribution. Based on transportation combination model, one can get both the volumes of travel demand allocation and transportation mode distribution to reflect the transfer of dynamic passenger flow between transportation modes and tourism destinations. However, the traditional transportation combination model is based on the multinomial logit model. Sun and Szeto (2021) propose a logit-based multi-class ridesharing user equilibrium assignment framework formulated as a mixed complementarity problem (MCP). Wang et al. (2020) develop a mixed behavioural equilibrium model with explicit consideration of mode choice (MBE-MC). For the model choice, traveller, following a logit modal split, selects among three options. Mi et al. (2015) establish the urban resident’s travel choice model in travel peak period on the condition of mixed traveling choices of cars and buses, based on the user equilibrium theory and the traffic bottleneck theory. These cannot reflect the nested structure characteristics of such choice as urban tourism travel destination. For the above analysis, considering the variability of urban tourism destination demand and the synchronization of the allocation of tourism travel and the distribution of transportation mode, this paper takes the super network method of equilibrium theory (Meng et al., 2014; Zhu et al., 2012) to establish the combined equilibrium model of tourism demand allocation and transportation distribution. Meanwhile, to avoid the negative characteristics of multinomial logit model with the independence of irrelevant alternatives (IIA), this paper constructs a double-deck arborescence nested structure of tourism travel destination choice to classify inner-city travel destination of the targeted city(hotel and scenic spots) based on the gross given tourism travel starting points. Through the establishment of the combined equilibrium model with variational inequality, it can get OD distribution of passenger flow and passenger flow allocation volume of transportation mode. This study will be helpful to reflect influential relationships between travel allocation volume and transportation mode, so as to provide universe tourism with technical support from the perspective of tourism facilities supply and transport services. The rest of the paper is organized as follows: Section 2 analyzes the characteristics of urban tourism travel endpoints; Section 3 constructs a super network based on nested Logit destination choice; Sections 4 gives the combined equilibrium condition of urban tourism transportation; Section
5 establishes the variational inequality model of the combined of tourism demand distribution and transportation distribution; Section 6 gives the solution algorithm of the combined model; Section 7 makes the analytical validation of examples; Section 8 provides some conclusive remarks of the paper.

2. Analysis of the characteristics of travel endpoints

After entering the tourist city through outer-city transportation channel, the travel endpoints of tourists show the following characteristics:

2.1. The travel demand of starting point is fixed

The starting points of the trip is the transit point for tourists entering the destination city, most of which are comprehensive passenger transfer hubs (tourism distribution centers) like airports, trains and high-speed rail stations, and passenger transportation stations. Some tourists enter the tourist city through chartered vehicles, self-driving cars or on-line car-hailing service. At this time, one can take the high-speed entrance (high-speed toll station, etc.) as the fixed virtual travel starting point. Actually, tourists’ choice of starting point for travel is essentially determined by their choice of out-of-city travel mode. Restricted by the mode of out-of-city travel mode, tourists cannot change the starting points of city travel. Therefore, the starting point of city travel can be regarded as a fixed-demand travel endpoint. It is much easier to obtain the passenger flow statistics of the comprehensive passenger transport hub or high-speed entrance and exit at the starting point. The demand statistics for passenger flow varies seasonally according to the characteristics of tourist attractions.

2.2. The travel demand of the destination point is variable

The final destination of travel generally includes tourist attractions and hotels. There are many tourist attractions and hotels for tourists to choose from in the tourist destination cities. Tourists’ choice of the final destination is a complex decision-making process that is greatly influenced by comprehensive factors as the popularity of tourist attractions or hotels, transportation convenience, affordability, personal preferences and others. What is more, some factors like the attractiveness of tourist attractions or hotels and transportation convenience change dynamically with the changing of tourist’s numbers. Therefore, the travel demand at the terminal end is dynamically variable.

2.3. The nested structure features of tourists’ choice of destination

After arriving in the tourist destination city, tourists’ choice preferences and the attractiveness of different types of travel destinations to them are different. So it is needed to fully consider the correlation between the various destinations. This paper divides the decision-making process of the travel destination into two steps: the first step is to choose a hotel destination or scenic destination, and the second step is to specifically choose a hotel or a scenic spot. Therefore, this paper takes a double-layer nest (Ma et al., 2020; Paredes-García & Castaño-Tostado, 2019) as the study structure, as shown in Figure 1, where the upper layer is the category (nest) of the end points, and the lower layer is all the selectable end points with each end point representing different nest. If a hotel is in or near the scenic area, just combine the two to and unify them as a scenic destination.

3. Super network based on nested logit destination choice

Compared with traditional traffic flow, the tourist flow feature of transport means as the carrier is more obvious, that is, the travel behavior of tourists pays less attention to the environment of carrier as road or track but pays more attention to the choice of the transportation carrier. Therefore, essentially, the choice of passenger flow transportation mode can be regarded as the issue of transportation distribution on tourism flow carrier. At this time, the tourist flow transportation network includes transportation routes of a certain means of transportation (or transportation mode) and transfer points, which respectively correspond to links and nodes in the transportation network diagram. Define the tourism transportation network \( G = (V, L) \), where \( V \) is a set of nodes, \( L \) is a set of transportation routes; \( l \) is a transportation route, \( l \in L \); \( O \) is a set of starting nodes, \( O \subset V \), and \( D \) is a set of ending nodes \( D \subset V \); \( r \) is a set of starting nodes, \( r \in O \), \( s \) is a termination node set, \( s \in D \); \( W \) is the set of OD pairs in the transportation network, \( \omega \) is an element in \( W \); \( K_{\omega} \) is the set of all transportation paths of OD pairs and \( \omega, k \in K_{\omega} \) is a

![Figure 1. Nested structure diagram of destination selection.](image-url)
transportation path of OD and \( q_\omega \); \( q_\omega \) is the tourism transportation demand volume of OD and \( \omega \); \( f_k \) is the tourism transportation volume on the transportation path \( k \in K_\omega \) of OD and \( \omega \); \( x_l \) is the tourism transportation volume on the transportation line \( l \); \( \delta_{lk} \) is the incidence relation between the transportation line and path, if the transportation line \( l \) is on the path \( k \), \( \delta_{lk} \) is 1. Otherwise, it is 0; \( x_l = \sum_{\omega \in W_{lb}} \sum_{k \in K_\omega} f_k \delta_{lk}, \forall l \in A; x_l = \sum_{\omega \in W_{lb}} \sum_{k \in K_\omega} f_k \delta_{lk}, \forall l \in B; c_l(x_l) \) is the transportation cost on transportation line \( l \), assuming it is a monotonically increasing function of transportation volume on transportation line \( l \), the functional form is shown in Equation (1).

\[
c_l(x_l) = c_l^0 + \theta t_l^0 [1 + \tau (x_l/N_l)\sigma]
\]  

(1)

This formula refers to the road traffic impedance function formula given by the Bureau of Public Roads (BPR) in the United States and applies the road impedance function to the traffic impedance of transportation lines. \( c_l^0 \) is the direct cost of the transportation route \( l \), mainly referring to the fare, toll, etc., which are generally relatively fixed; \( \theta \) is the time value of tourists (unit: yuan/min), the average time value of tourists on each transportation line can be obtained through investigation and statistics, and be classified according to the statistical results. For example, the time value can be divided into high time value, medium time value and low time value, please refer to literature (Liu et al., 2021); \( t_l^0 \) is the travel time of tourist using transportation line \( l \), including travel time by the vehicle and the waiting time with the impact of road traffic in the city considered; \( x_l \) is the tourist flow on the transportation line \( l \); \( N_l \) is the transportation capacity of the transportation mode on the transportation line \( l \), that is, the maximum number of passengers that can be transported at a unit time; \( x_l/N_l \) shows that the closer the tourist flow on transportation line \( l \) to the transportation capacity, the longer of the travel time and the higher of the travel cost \( c_l(x_l) \); \( \tau \) and \( \sigma \) are the parameters to be calibrated, the recommended value of American BPR formula is \( \tau = 0.15 \) and \( \sigma = 4 \).

To simplify the combined problem of travel destination category separation and transportation volume allocation to the same transportation network problem, this paper introduces the concept of super network where tourism flow transportation was established as shown in Figure 2 by adding a virtual transportation line with zero impedance to the original transportation network. The network is based on vehicles, which is different from the traditional traffic network based on roads. When a transport route stops at multiple destinations, in which the first destination serves as both a switching node and a travel destination. The model of this study works as long as there is an impedance time of the transport line between two destinations. If the tourists arrive at the second destination after completing their travel at the first destination, the new starting and ending point is \( r \rightarrow s \). The network includes two sub-networks: a hotel-type sub-network that ends in a hotel and a scenic spot-type sub-network that ends in a scenic spot, where the travel starting point \( r \) and hotel-type sub-network \( r \) are connected with scenic spot-type sub-network \( r \) like \( r \rightarrow \hat{r}, \hat{r} \rightarrow r \) and \( \hat{s} \rightarrow s \), which are all virtual transportation routes with zero cost. For the convenience of expression, \( a \) and \( b \), respectively corresponds to the hotel-type sub-network and the scenic spot-type sub-network, \( W_a \) indicates OD pair set of the hotel-type sub-network, \( W_b \) indicates OD pair set of the scenic-spot sub-network. \( W = W_a \cup W_b \); A and B represent the collection of transportation routes in the sub-network of hotel category and scenic spot, respectively.

4. Combined equilibrium conditions

If the total amount of trips generated by starting node \( r \) and \( \forall r \), \( q_\omega^a \) and \( q_\omega^b \) represent the tourism transportation demand of the starting point and the destination through the hotel network and the scenic spot network respectively, then the constraints are \( q_\omega^a + q_\omega^b = O_r \) and \( \forall \omega \in W, r \in O \), then the travel demand matrix \( Q = \{q_{\omega r}\} \) is taken to reflect the variability of tourism travel demand, that is, considering how the traveler on the starting node \( r \) chooses the travel destination. Generally speaking, after a tourist selects a certain nest, there are mainly two factors that further affect the choice of destination: one is the impedance from the starting point \( r \) to the destination \( s \), the other is the attraction degree of the destination \( s \). For the former one, each tourist tries to choose the destination \( s \) with the smallest travel cost from the starting point \( r \), that is, the shortest travel route results in the smallest cost impedance \( \mu_{rs} \); for the latter, tourists generally choose the travel destination with the greatest degree of attraction. The attractive ability of each termination node is related to the popularity of the scenic spot (hotel popularity), cost, personal preference, etc. Here \( \phi_\omega^a \) and \( \phi_\omega^b \) represent the attractiveness measure of the hotel
endpoint and scenic spot, respectively, $\phi^a_{\alpha}$ and $\phi^b_{\beta}$ represent the attractiveness measure of the endpoint $\hat{s}$ and the endpoint $\hat{s}$, respectively. Assuming that all attractiveness measures can be converted into units of measure equivalent to costs, the larger the value of the attractiveness measure, the stronger the attractiveness. Therefore, tourists always try to choose the travel destination with the smallest cost impedance and the largest attractiveness measure, saying, the smallest destination of $\omega - \phi^a_{\alpha}$ or $\mu_{\beta} - \phi^b_{\beta}$. It is defined as the comprehensive tourism impedance.

In order to reflect the attribute difference of travel destination itself and tourist’s preference, this paper divides travel destinations two nests in the super network graph.

By introducing nested Logit model (Han et al., 2020; Kim et al., 2020), the thesis describes the choice of travel destination for tourists. Assuming that $S^a$ and $S^b$ are the number of hotel destinations and the scenic destination, respectively, here comes the travel demand function of the hotel destination:

$$q^a_{rs} = O_r \cdot \frac{\exp(-\alpha(\mu^a_{\omega} - \phi^a_{a}))}{\exp(-\alpha(\mu^a_{\omega} - \phi^a_{a})) + \exp(-\alpha(\mu^b_{\omega} - \phi^b_{b}))} \cdot \frac{\exp(-\beta(\mu^b_{\omega} - \phi^b_{b}))}{\sum_{s \in S^a} \exp(-\beta(\mu^b_{\omega} - \phi^b_{b}))},$$

$\forall \omega \in W_a, (r, s) \in W_a, r \in O, s \in S^a$ \hspace{1cm} (2)

In this demand function, $q^a_{rs}$ represents the travel demand of hotel selection category with $r$ as the starting point and $\hat{s}$ as the destination, where $\alpha$ and $\beta$ are the parameters to be calibrated in the model, and $\frac{\alpha}{\beta}$ is the inter-layer scale parameter of the nested Logit model, $0 < \frac{\alpha}{\beta} \leq 1$. When $\alpha = \beta$, it degrades into multinomial logit model. In the hotel network or scenic spot network, tourists are basically aware of the cost of transportation routes. Therefore, this paper takes the Wardrop user equilibrium principle to reflect the transportation route selection, where $\mu^a_{\omega}$ is the minimum cost from the starting point $r$ to the destination $\hat{s}$ in the hotel network.

However, when choosing the hotel destination and scenic destination, tourist’s cognition is stochastic. So the thesis takes the Logit stochastic user equilibrium principle, where $\mu^a_{\omega}$ is the expected cost of OD pair and $\omega$ in the super network, namely

$$\mu^a_{\omega} = \frac{1}{\beta} \ln \sum_{\hat{s} \in S^a} \exp(-\beta(\mu^b_{\omega} - \phi^b_{\beta})),$$

$\omega \in W_a, (r, \hat{s}) \in W_a, r \in O, \hat{s} \in S^a$ \hspace{1cm} (3)

Similarly, one gets the travel demand function of the destination of scenic spots.

**Definition 4.1:** (the combined equilibrium distribution condition of tourism demand distribution and transportation distribution) Under the equilibrium state, no tourists can reduce their travel expenses by changing the transportation route in the tourism passenger flow transportation network, and the choice of travel destination satisfies the nested Logit model (2).

Equation 4.1 contains two kinds of equilibrium, one is the deterministic equilibrium of transportation route selection, the other is the nested Logit stochastic equilibrium of travel destination selection. See the following mathematical expressions:

$$(c^a_k - \mu^a_{\omega})f_k = 0, c^a_k - \mu^a_{\omega} \geq 0, \forall k \in K^a, (r, \hat{s}) \in W_a, r \in O \hspace{1cm} (4)$$

$$(c^b_k - \mu^b_{\omega})f_k = 0, c^b_k - \mu^b_{\omega} \geq 0, \forall k \in K^b, (r, \hat{s}) \in W_b, r \in O \hspace{1cm} (5)$$

$$q^a_{rs} = O_r \cdot \frac{\exp(-\alpha(\mu^a_{\omega} - \phi^a_{a}))}{\exp(-\alpha(\mu^a_{\omega} - \phi^a_{a})) + \exp(-\alpha(\mu^b_{\omega} - \phi^b_{b}))} \cdot \frac{\exp(-\beta(\mu^b_{\omega} - \phi^b_{b}))}{\sum_{s \in S^a} \exp(-\beta(\mu^b_{\omega} - \phi^b_{b}))},$$

$\forall \omega \in W_a, (r, \hat{s}) \in W_a, r \in O, \hat{s} \in S^a$ \hspace{1cm} (6)

$$q^b_{rs} = O_r \cdot \frac{\exp(-\alpha(\mu^b_{\omega} - \phi^b_{b}))}{\exp(-\alpha(\mu^b_{\omega} - \phi^b_{b})) + \exp(-\alpha(\mu^b_{\omega} - \phi^b_{b}))} \cdot \frac{\exp(-\beta(\mu^b_{\omega} - \phi^b_{b}))}{\sum_{s \in S^b} \exp(-\beta(\mu^b_{\omega} - \phi^b_{b}))},$$

$\forall \omega \in W_b, (r, \hat{s}) \in W_b, r \in O, \hat{s} \in S^b$ \hspace{1cm} (7)

Among them, the cost of transportation path $k \in K^a_{\omega}$ of OD pair and $\omega$ in the hotel network is $c^a_k = \sum_{l \in A} c(l) \delta_{lk}$, and the cost of the transportation path $k \in K^b_{\omega}$ of OD pair and $\omega$ in the scenic network is $c^b_k = \sum_{l \in B} c(l) \delta_{lk}$, $\mu^a_{\omega}$ is the minimum cost between the OD pair and $(r, \hat{s})$ in the hotel network, and $\mu^b_{\omega}$ is the minimum cost between OD pair and $(r, \hat{s})$ in the scenic network.

**5. Combination model**

**5.1. Constraints**

If the OD flow and transport route flow in the tourism transportation network satisfy the following equation and inequality constraints:

$$q^a_{\omega} + q^b_{\omega} = O_r, \forall \omega \in W, r \in O, (\lambda_{\omega}),$$

$$\sum_{s \in S^a} q^a_{rs} = q^a_{\omega}, \forall \omega \in W_a, r \in O, (\mu^a_{\omega}),$$

$$\sum_{s \in S^b} q^b_{rs} = q^b_{\omega}, \forall \omega \in W_b, r \in O, (\mu^b_{\omega}),$$

$$c^a_k - \mu^a_{\omega} \geq 0, \forall k \in K^a, (r, \hat{s}) \in W_a, r \in O \hspace{1cm} (8)$$

$$c^b_k - \mu^b_{\omega} \geq 0, \forall k \in K^b, (r, \hat{s}) \in W_b, r \in O \hspace{1cm} (9)$$
\[
\sum_{s \in S^b} q^{b}_{rs} = q^b_{\omega}, \forall \omega \in W_b, r \in O, (\mu^b_{\omega}),
\]
(10)
\[
\sum_{k \in K^a} f_k = q^a_{\omega r}, \forall (r, s) \in W_{dr}, r \in O, (\mu^a_{\omega}),
\]
(11)
\[
\sum_{k \in K^b} f_k = q^b_{rs}, \forall (r, s) \in W_{dr}, r \in O, (\mu^b_{\omega}),
\]
(12)

It is feasible. Wherein, Equation (8) represents the conservation condition that the total amount of starting nodes is divided by two kinds of endpoints. Equation (9) indicates that the total demand for hotel network OD pair and \( \omega \) equals to all the sum of transportation volume with \( r \) as the starting point and \( s \) as the destination in OD pair; Equation (10) indicates that the total demand for scenic spot network OD pair and \( \omega \) equals to all the sum of transportation volume with \( r \) as the starting point and \( s \) as the destination in OD pair; Equation (11) represents the relationship between the OD demand and the route transportation volume in the hotel network; Equation (12) represents the relationship between the OD demand and the route transportation volume in the scenic spot network; the variables represented by Greek letters in parentheses after each equation are the corresponding dual variables or shadow price. In addition, there are the following illustrative constraints:

\[
x_l = \sum_{\omega \in W_a} \sum_{k \in K^a} f_k \delta_{lk}, \forall l \in A
\]
(16)
\[
x_l = \sum_{\omega \in W_b} \sum_{k \in K^b} f_k \delta_{lk}, \forall l \in B
\]
(17)
\[
q_s = \sum_{\omega \in W_a} q^a_{\omega s}, \forall s \in S^a
\]
(18)
\[
q_s = \sum_{\omega \in W_b} q^b_{s\omega}, \forall s \in S^b
\]
(19)

Among them, Equations (16) and (17) represent the transportation volume relationship between transportation line and transportation route in the hotel network and the scenic spot network, respectively; Equation (18) indicates that the tourism arrival volume of the hotel terminal \( s \) is equal to all OD pairs to its terminals in the road network. Equation (19) indicates that the tourism arrival volume of the scenic spot terminal \( s \) is equal to all OD pairs to its terminals in the road network.

### 5.2. Variational inequality model

Due to the complex structure of the nested model of travel demand function, the utility and transportation volume distribution in the model restrict each other: the travel utility is affected by the transportation volume, while the transportation distribution volume and allocation volume are determined by the utility, and finally reach a balance. For the tourism transportation super network selected by the nested Logit endpoint. To simultaneously obtain the demand distribution of tourist destinations and the allocation of transportation routes, a combination model of variational inequality is constructed as follows:

\[
\sum_{l \in \{A, B\}} c_l(x^*_l) (x_l - x^*_l)
\]
(VI) \[
+ \sum_{\omega \in W_a} \left( \frac{1}{\alpha} \ln \frac{q^a_{\omega r}}{q^a_{\omega r} - \phi^a_{\omega r}} \right) (q^a_{\omega r} - q^a_{\omega r}^*)
\]
\[
+ \sum_{\omega \in W_b} \left( \frac{1}{\beta} \ln \frac{q^b_{s\omega}}{q^b_{s\omega} - \phi^b_{s\omega}} \right) (q^b_{s\omega} - q^b_{s\omega}^*)
\]
\[
+ \sum_{\omega \in W_a} \sum_{\tilde{s} \in S^a} \left( \frac{1}{\alpha} \ln \frac{q^a_{\omega r}}{q^a_{\omega r} - \phi^a_{\omega r}} \right) (q^a_{\omega r} - q^a_{\omega r}^*)
\]
\[
+ \sum_{\omega \in W_b} \sum_{\tilde{s} \in S^b} \left( \frac{1}{\beta} \ln \frac{q^b_{s\omega}}{q^b_{s\omega} - \phi^b_{s\omega}} \right) (q^b_{s\omega} - q^b_{s\omega}^*) \geq 0
\]

The feasible region is \((f_k, x_l, q^a_{\omega r}, q^b_{s\omega}, q^a_{\omega r}^*, q^b_{s\omega}^*) \in \Omega = \{(9) - (20)\}, where the variable marked (*) is the desired solution.

**Theorem 5.1:** The variational inequality model (VI) is equivalent to the combined equilibrium condition (4)–(7) of tourism transportation network.

**Proof:** Based on the K-K-T condition of variational inequality model (VI), then

\[
\left[ \sum_{l \in A} c_l(x^*_l) \delta_{lk} - \mu^a_{\omega r} \right] f_k = 0, \sum_{l \in A} c_l(x^*_l) \delta_{lk} - \mu^a_{\omega r} \geq 0, \quad k \in K^a, (r, s) \in W_{dr}, r \in O
\]
(20)
\[
\left[ \sum_{l \in B} c_l(x^*_l) \delta_{lk} - \mu^b_{s\omega} \right] f_k = 0, \sum_{l \in B} c_l(x^*_l) \delta_{lk} - \mu^b_{s\omega} \geq 0, \quad k \in K^b, (r, s) \in W_{dr}, r \in O
\]
(21)
\[
\left( \frac{1}{\alpha} \ln \frac{q^a_{\omega r}}{q^a_{\omega r} - \phi^a_{\omega r}} - \lambda_{\omega r} + \mu^a_{\omega r} \right) q^a_{\omega r} = 0,
\]
\[
\left( \frac{1}{\beta} \ln \frac{q^b_{s\omega}}{q^b_{s\omega} - \phi^b_{s\omega}} - \lambda_{s\omega} + \mu^b_{s\omega} \right) q^b_{s\omega} \geq 0, \quad \omega \in W, r \in O
\]
(22)
Thus, 

\[
\begin{aligned}
\frac{1}{\alpha} \ln \frac{q^b_{\omega \alpha}}{q_{\omega \alpha}^b} - \frac{1}{\alpha} \ln \frac{q^a_{\omega \alpha}}{q_{\omega \alpha}^a} - \lambda_{\omega \alpha} + \mu_{\omega \alpha} &= 0, \\
\frac{1}{\beta} \ln \frac{q^\beta_{\omega \rho}}{q_{\omega \rho}^\beta} - \frac{1}{\beta} \ln \frac{q^\alpha_{\omega \rho}}{q_{\omega \rho}^\alpha} - \lambda_{\omega \rho} + \mu_{\omega \rho} &= 0,
\end{aligned}
\]

(23)

From Equations (22) and (23), here are:

If \( q^a_{\omega \alpha} > 0 \), then

\[
\begin{aligned}
\frac{1}{\alpha} \ln \frac{q^a_{\omega \alpha}}{q_{\omega \alpha}^a} - \frac{1}{\alpha} \ln \frac{q^a\langle \omega \rangle}{q_{\omega}^a} - \lambda_{\omega \alpha} + \mu_{\omega \alpha} &= 0, \\
&\omega \in W, r \in O
\end{aligned}
\]

(30)

and \( q^b_{\omega \alpha} > 0 \), then

\[
\begin{aligned}
\frac{1}{\alpha} \ln \frac{q^b_{\omega \alpha}}{q_{\omega \alpha}^b} - \frac{1}{\alpha} \ln \frac{q^b\langle \omega \rangle}{q_{\omega}^b} - \lambda_{\omega \alpha} + \mu_{\omega \alpha} &= 0, \\
&\omega \in W, r \in O
\end{aligned}
\]

(31)

Equations (30) and (31) can be written separately like:

\[\begin{aligned}
q^a_{\omega \alpha} = \exp(\alpha \lambda_{\omega \alpha}) \cdot \exp[-\alpha(\mu_{\omega \alpha} - \phi^\alpha_{\omega \alpha})], \omega \in W, r \in O \\
q^b_{\omega \alpha} = \exp(\alpha \lambda_{\omega \alpha}) \cdot \exp[-\alpha(\mu_{\omega \alpha} - \phi^\beta_{\omega \alpha})], \omega \in W, r \in O
\end{aligned}\]

(32)

(33)

Plus Equations (32) and (33) and pay attention to the conservation condition (8), here is

\[1 = \exp(\alpha \lambda_{\omega \alpha}) \cdot \left\{ \frac{\exp[-\alpha(\mu_{\omega \alpha} - \phi^\alpha_{\omega \alpha})]}{\exp[-\alpha(\mu_{\omega \alpha} - \phi^\beta_{\omega \alpha})]} + \frac{\exp[-\alpha(\mu_{\omega \alpha} - \phi^\beta_{\omega \alpha})]}{\exp[-\alpha(\mu_{\omega \alpha} - \phi^\alpha_{\omega \alpha})]} \right\}\]

(34)

Thus, \( \lambda_{\omega \alpha} \) is the expected cost of travel of OD pairs and \( \omega \). Substituting \( \exp(\alpha \lambda_{\omega \alpha}) \) in Equations (34) into (32), here is the Logit model of tourists choosing hotels as destinations:

\[\begin{aligned}
q^a_{\omega \alpha} &= \frac{\exp[-\alpha(\mu_{\omega \alpha} - \phi^\alpha_{\omega \alpha})]}{\exp[-\alpha(\mu_{\omega \alpha} - \phi^\beta_{\omega \alpha})] + \exp[-\alpha(\mu_{\omega \alpha} - \phi^\beta_{\omega \alpha})]}, \\
&\omega \in W, r \in O
\end{aligned}\]

(35)

By multiplying Equations (35) and (29), here is the nested Logit model of tourists choosing a hotel as the travel destination:

\[\begin{aligned}
\frac{q^a_{\omega \alpha}}{q_{\omega \alpha}^a} &= \frac{q^a_{\omega \rho} \cdot q_{\omega \rho}^a}{q_{\omega \alpha}^a} = \frac{q^a_{\omega \rho}}{q_{\omega \rho}^a} \\
&= \frac{\exp[-\alpha(\mu_{\omega \alpha} - \phi^\alpha_{\omega \alpha})]}{\exp[-\alpha(\mu_{\omega \alpha} - \phi^\beta_{\omega \alpha})] + \exp[-\alpha(\mu_{\omega \alpha} - \phi^\beta_{\omega \alpha})]} \\
&\quad \cdot \sum_{s \in S^\beta} \exp[-\beta(\mu_{s \rho} - \phi^\beta_{s \rho})]
\end{aligned}\]

(36)

Namely, Equation (6). Similarly, here is the nested Logit model (7) of tourists choosing a scenic spot as the travel destination.

Proved.

\[\square\]

6. Solving algorithm

The feasible region of variational inequality model (VI) is composed of linear constraints, so it is a compact convex
set, and the function \( c_i(x_i), \ln q_{\alpha_i}^a, \ln q_{\alpha_i}^b, \ln q_{\alpha_i}^a, \ln q_{\alpha_i}^b \) are continuous. According to Brouwer’s fixed point theorem, it is clear that there is at least one solution to the model (VI), and then by the monotonicity assumption of \( c_i(x_i), \) model (VI) has a unique solution. Based on the MSA (Method of Successive Average) method (Botte et al., 2020), the solution algorithm is designed as follows:

Step 1: Initialization. Calculate various costs of OD pairs according to the ‘zero flow’ transportation line time, complete the initial end point demand division \( d_{\alpha_i}^{(1)} \) and \( q_{\alpha_i}^{(1)} \) by nested Logit model, and then set the number of iterations \( n = 1 \).

Step 2: Calculate transportation costs \( c_i^{(n)}(x_i^{(n)}), i \in \{A, B\} \).

Step 3: On the basis of \( \{c_i^{(n)}\} \), find out the shortest transportation path from each starting point \( r \) to all destinations in the hotel subnetwork and scenic subnetwork, calculate its costs \( \mu_{r_i}^{(n)}, \mu_{r_i}^{(n)} \) and \( \mu_{r_i}^{(n)}, \mu_{r_i}^{(n)} \), and calculate the expected costs \( \omega_{\alpha_i}^{(n)} \) and \( \omega_{\alpha_i}^{(n)} \).

Step 4: Calculate the demand for auxiliary travel \( g_{\alpha_i}^{(n)} \) and \( g_{\alpha_i}^{(n)} \)

\[
\begin{align*}
g_{\alpha_i}^{(n)} &= O_r \cdot \frac{\exp[-\alpha(\mu_{\alpha_i}^{(n)} - \omega_{\alpha_i}^{(n)})]}{\sum_{l \in \mathcal{S}} \exp[-\alpha(\mu_{\alpha_i}^{(n)} - \omega_{\alpha_i}^{(n)})] + \exp[-\alpha(\mu_{\omega}^{(n)} - \omega_{\alpha_i}^{(n)})]} + \frac{\exp[-\beta(\mu_{r_i}^{(n)} - \phi_{\alpha_i}^{(n)})]}{\sum_{l \in \mathcal{S}} \exp[-\beta(\mu_{r_i}^{(n)} - \phi_{\alpha_i}^{(n)})] + \exp[-\beta(\mu_{\omega}^{(n)} - \phi_{\alpha_i}^{(n)})]} \\
g_{\alpha_i}^{(n)} &= O_r \cdot \frac{\exp[-\alpha(\mu_{\alpha_i}^{(n)} - \omega_{\alpha_i}^{(n)})]}{\sum_{l \in \mathcal{S}} \exp[-\alpha(\mu_{\alpha_i}^{(n)} - \omega_{\alpha_i}^{(n)})] + \exp[-\alpha(\mu_{\omega}^{(n)} - \omega_{\alpha_i}^{(n)})]} + \frac{\exp[-\beta(\mu_{r_i}^{(n)} - \phi_{\alpha_i}^{(n)})]}{\sum_{l \in \mathcal{S}} \exp[-\beta(\mu_{r_i}^{(n)} - \phi_{\alpha_i}^{(n)})] + \exp[-\beta(\mu_{\omega}^{(n)} - \phi_{\alpha_i}^{(n)})]}
\end{align*}
\]

Step 5: Perform deterministic balanced allocation of deterministic users in the hotel sub-network and the scenic sub-network respectively to obtain the passenger flow of the auxiliary transportation line in the equilibrium state \( y_{\lambda_i}^{(n)}, i \in \{A, B\} \).

Step 6: Update various flows using MSA method

\[
\begin{align*}
q_{\alpha_i}^{(n+1)} &= q_{\alpha_i}^{(n)} + \frac{1}{n+1} (g_{\alpha_i}^{(n)} - q_{\alpha_i}^{(n)}) \\
q_{\alpha_i}^{(n+1)} &= q_{\alpha_i}^{(n)} + \frac{1}{n+1} (g_{\alpha_i}^{(n)} - q_{\alpha_i}^{(n)}) \\
x_{\lambda_i}^{(n+1)} &= x_{\lambda_i}^{(n)} + \frac{1}{n+1} (y_{\lambda_i}^{(n)} - x_{\lambda_i}^{(n)})
\end{align*}
\]

Step 7: If meeting the convergence requirements, terminate the algorithm; otherwise, let \( n = n + 1 \), and return to Step 2.

7. Illustrative example

Taking the tourism flow transportation network of Huangshan City as the prototype, this paper designs a simple transportation network to illustrate the feasibility of the model. As shown in Figure 3, there are 10 nodes and 28 transportation lines (road segments) in the transportation network. Nodes C and D are the starting points of tourist travel in the city area, assuming to represent Huangshan High-speed Railway Station and Huangshan Airport respectively; Nodes G1 and G2 are intermediate transfer nodes, not generating and consuming tourist passenger flow (transfer time has been counted on the downstream transportation routes); Nodes A1, A2, and A3 are three hotel travel destinations, and nodes B1, B2, and B3 are three scenic travel destinations; transportation routes 1–28 are directed arcs from the start point to the end point.

Referring to the tourist passenger flow data in 2019 provided by Huangshan Tourism Transportation Development Co., Ltd., combined with the statistical data resources disclosed on the Internet, the basic data of the Huangshan tourism transportation network is now defined as shown in Table 1 (calculating based on the average daily data in the peak tourist season). The total travel demand at the starting point of
city travel is $O_C = 1900$ people/hour, $O_D = 1500$ people/hour (assuming that the tourism travel volume in the total demand for travel starting in the city has been separated). Table 2 shows basic data table of attractiveness measurement. The other parameters in the model are: $\alpha = 0.01$, $\beta = 0.1$, $\theta = 2$.

The cost impedance of the transportation route is in the form of formula (1), the termination index of the algorithm is set to 0.001, and the variational inequality model (VI) is used to calculate the test network. After 18 iterations, the accuracy requirements are met. Figure 4 shows the iterative convergence figure of solution algorithm. Tables 3 and 4 show the travel demand on each OD point pair and the distribution results of tourist passenger flow of each transportation route.

The inter-layer scale parameter of the tourism travel demand distribution model of Nested Logit $\beta$ reflects the correlation degree of the transportation route selection branches under each destination category. When $\alpha$ is closer to $\beta$, the correlation between the selected branches of the transportation route under the same category end point is smaller and when $\alpha$ is closer to 0, the greater the correlation between the selected branches. As shown in Figure 5, taking the travel starting point C as an example, when $\alpha$ continues to increase, the overall trend is that the demand for scenic spots increases significantly, while the hotel end A1 decreases the most obviously, and A3 increases slightly. Because with the increase of the value $\alpha$, the difference of each transportation route is greater, the choice of destination for tourists is closer to the deterministic choice. So the tourist is expected to choose the transportation route with the smallest comprehensive tourism impedance. The tourism comprehensive impedance of scenic spot terminal B2 is the smallest, and the hotel terminal A1 has the largest tourism comprehensive impedance, so the demand for B2 increases the most obviously, and the demand for A1 decreases the most obviously. When $\alpha = \beta$, the nest Logist degrades into a multinomial logit model. Comparing the calculation results of $\alpha = 0.01$ and $\alpha = 0.1$, it is clear that in the multinomial logit model, tourists only choose the maximum comprehensive utility of the transportation route, while the nested Logit model fully considers the attractiveness measure of hotel destinations and scenic spots destinations, reflecting the correlation between the transportation route selection branches under the same class, and is more in line with the choice behavior of tourists when choosing transportation routes.

To make it more specific, there is also a test for the impact of different types of time values on the distribution of tourist traffic. In the test network, the time value of tourists from the starting point D to the end point A1 is 1, and the time value of tourists starting from C to the end point A1 is 3. Other parameters remain unchanged. Compared with the original time value $\theta = 2$, define $\theta = 1$ the tourists with low time value and $\theta = 3$ the tourists with

### Table 2. Basic data table of attractiveness measurement.

| Starting-ending point | Starting-ending point | Starting-ending point | Starting-ending point |
|-----------------------|-----------------------|-----------------------|-----------------------|
| $C \rightarrow \tilde{A}$ | 15                     | $C \rightarrow A_1$ | 20                    |
| $C \rightarrow \tilde{A}$ | 10                     | $C \rightarrow A_2$ | 15                    |
| $D \rightarrow \tilde{A}$ | 30                     | $D \rightarrow A_1$ | 10                    |
| $D \rightarrow \tilde{A}$ | 10                     | $D \rightarrow A_2$ | 12                    |

### Table 3. Results of trip distribution in the experimental network (unit: person/hour).

| Starting-ending point | Distribution volume | Starting-ending point | Distribution volume |
|-----------------------|---------------------|-----------------------|---------------------|
| C→A1                  | 544                 | D→A1                 | 398                 |
| C→A2                  | 389                 | D→A2                 | 336                 |
| C→A3                  | 227                 | D→A3                 | 283                 |
| C→B1                  | 295                 | D→B1                 | 194                 |
| C→B2                  | 255                 | D→B2                 | 155                 |
| C→B3                  | 190                 | D→B3                 | 134                 |

### Table 4. Results of tourist flow assignment in the experimental network (unit: person/hour).

| No. of transportation route | Passenger flow volume | No. of transportation route | Passenger flow volume |
|----------------------------|-----------------------|----------------------------|-----------------------|
| 1                          | 245                   | 15                         | 119                   |
| 2                          | 283                   | 16                         | 93                    |
| 3                          | 188                   | 17                         | 136                   |
| 4                          | 306                   | 18                         | 56                    |
| 5                          | 112                   | 19                         | 288                   |
| 6                          | 205                   | 20                         | 198                   |
| 7                          | 172                   | 21                         | 135                   |
| 8                          | 73                    | 22                         | 235                   |
| 9                          | 99                    | 23                         | 164                   |
| 10                         | 226                   | 24                         | 95                    |
| 11                         | 138                   | 25                         | 102                   |
| 12                         | 184                   | 26                         | 62                    |
| 13                         | 115                   | 27                         | 43                    |
| 14                         | 96                    | 28                         | 178                   |
Table 1. Basic data table of tourism transportation network in Huangshan City.

| Transportation route no. | $c_i^0$ (unit: Yuan) | $t_i^0$ (unit: min) | $N_i$ (unit: person/hour) | Transportation route no. | $c_i^0$ (unit: Yuan) | $t_i^0$ (unit: min) | $N_i$ (unit: person/hour) |
|--------------------------|----------------------|---------------------|---------------------------|--------------------------|----------------------|---------------------|---------------------------|
| 1                        | 80                   | 30                  | 250                       | 15                       | 15                   | 40                  | 150                       |
| 2                        | 30                   | 100                 | 300                       | 16                       | 4                    | 50                  | 300                       |
| 3                        | 160                  | 80                  | 250                       | 17                       | 8                    | 20                  | 150                       |
| 4                        | 5                    | 60                  | 500                       | 18                       | 6                    | 70                  | 300                       |
| 5                        | 100                  | 55                  | 250                       | 19                       | 40                   | 20                  | 300                       |
| 6                        | 90                   | 45                  | 250                       | 20                       | 20                   | 60                  | 200                       |
| 7                        | 4                    | 50                  | 300                       | 21                       | 90                   | 45                  | 250                       |
| 8                        | 100                  | 45                  | 200                       | 22                       | 4                    | 55                  | 300                       |
| 9                        | 25                   | 80                  | 100                       | 23                       | 70                   | 35                  | 250                       |
| 10                       | 40                   | 20                  | 250                       | 24                       | 70                   | 35                  | 250                       |
| 11                       | 5                    | 60                  | 300                       | 25                       | 2                    | 40                  | 300                       |
| 12                       | 10                   | 30                  | 200                       | 26                       | 60                   | 30                  | 250                       |
| 13                       | 4                    | 50                  | 200                       | 27                       | 20                   | 55                  | 100                       |
| 14                       | 10                   | 25                  | 100                       | 28                       | 30                   | 15                  | 250                       |

Figure 5. Each tourist demand under different $\alpha$.

Figure 6. Distribution results of tourist flow under different types of time value.

high time value. There are three transportation routes 20, 21, 19→11 between the origin and destination D→A1, and three transportation routes 2, 3, 1→11 between the origin and destination C→A1. Figure 6 shows the distribution results of tourist traffic for different types of time values. It can be seen that the demand C→A1 is still 544 person/h, while the demand D→A1 increases to 421 person/h. This is due to the change in the time value of tourists D→A1, making the change of minimum travel composite impedance from the starting point D to the hotel end point.

In addition, the passenger flow of transportation route 21 decreased significantly, and the passenger flow of transportation routes 20 and 19→11 increased significantly, indicating that tourists with low time value are constantly shifting to low-cost impedance routes. In transportation route 3, passenger flow increases significantly, and transportation route 2 and 1→11 has a certain decrease in the passenger flow, indicating that for tourists with high time value, the cost impedance path with high original fare has begun to transfer to a low-cost impedance path, and tourists will consider more on transportation with short travel time. Therefore, the time value type of tourists has a great influence on the calculation results of the model. In practical application, the method of investigation and statistics should be combined to reasonably determine the time value type of tourists in each transportation route.

8. Conclusion

From the perspective of application, this study puts forward a new method of classifying tourists transportation modes at the municipal scale, which provides theoretical support for the allocation of transportation resources and tourism service management of tourist cities. From the theoretical perspective, traditional disaggregate tourism modes of transportation division method requires given travel OD distributions and considers little about the interaction between the choice of transportation mode
and OD distribution. Therefore, to solve the above problem, it proposes the combined model of traffic distribution and traffic flow allocation. Meanwhile, traditional combined model is based on multinomial Logit, while the author considers that the choice of travel destination in the city conforms to the two-layer tree nest structure. So, this paper proposes a research idea for the construction of a combined model of tourism passenger flow and transportation with the characteristics of nested Logit structure, fixed starting point demand and variable destination demand for urban tourism travel. The variational inequality combination model and algorithm proposed in this paper are also verified as effective by analyzing and testing a simplified example of Huangshan City’s tourism transportation network for the volume of city tourism travel distribution and transportation distribution. This study expands the application of the combined transport model.

The analysis of inter-layer proportional parameter of the Nested Logit $\alpha$ shows that the Nested Logit model fully considers the attractiveness measure of the hotel endpoint and the scenic spot endpoint and reflects the correlation between the transportation route selection branches under the same category, which is more in line with the choice behavior of tourists when choosing transportation routes compared to multinomial logit model.

From the analysis of the influence of different types of time value on the model calculation results, the type of tourist’s time value has a greater impact on the comprehensive tourism impedance of the transportation route. In practical application, it is necessary to combine the methods of investigation and statistics to reasonably determine the type of tourist time value of each transportation route, so as to obtain more accurate calculation results.

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