

# RESEARCH ON MULTIMODAL TRAFFIC PATH PLANNING PROBLEM

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## ABSTRACT

Under the background of rapid growth of residents' travel demand and diversification of travel modes, this essay transforms multi-mode travel behavior into a multi-stage decision-making process by analyzing travelers' decision-making behavior. In the decision-making of travel path, the dynamic programming theory is introduced, and the decision is made in stages with the lowest generalized travel cost as the goal, and finally the best travel path and corresponding travel mode are obtained. Finally, taking a certain area of Nanjing as an example, a dynamic programming standard model is constructed according to the actual situation of public transport routes. According to the calibration of relevant parameters under the target, the model is solved, and the decision-making scheme is finally obtained.

## 1. INTRODUCTION

Traffic travel has always been an indispensable part of residents' lives. With the continuous improvement of urbanization rate and the improvement of infrastructure, the number of travel modes available for people to choose is also increasing. The choice of residents' travel modes has shifted from a single simple mode to diversification. A complete trip often requires the cooperation of multiple transportation modes. Therefore, it is of great significance to construct a multi-mode traffic network based on the actual situation, explore people's travel behavior, provide decision-making suggestions for travelers, and reasonably guide people to travel.

Foreign research on traffic path planning started earlier, and there are a number of results in the literature. Initially, experts and scholars mainly focused on road network planning research, generally for a single mode of traffic shortest path planning, that is, to find the shortest path between the starting point and the destination. Pujol et al. used a path planning algorithm using morphological operations and DSP image processing and applied it in path planning to determine the shortest path between two different locations in a fragmented environment (Pujol et al., 2002). In the multi-mode path planning, Angelica Lozano et al. used label correction technology to find the shortest feasible path from the starting point to the destination in the multi-modal transportation network and proposed a temporary modification of the timing algorithm to solve the shortest feasible path problem of multiple modes of transportation. The shortest path planning was carried out based on travel cost and transfer times (Lozano et al., 2001).

In recent years, China's transportation industry has developed rapidly, and the research on related traffic problems has also made great progress. Multi-mode traffic path planning is favored by many experts and scholars. Zhou Jiali et al. established a multi-mode traffic network and considered the timetable factors of public transportation to recommend the

fastest route to the destination and the required time for travelers (Zhou Jiali et al., 2017). Zhao Ting et al. considered the influence of departure timetable when studying urban multi-mode traffic travel and provided travelers with the optimal decision with the least travel cost (Zhao Ting et al., 2019). Li Haonan et al. considered the influence of time fluctuation and emergencies and established a route decision model and algorithm of multi-mode traffic network based on Markov decision process to save travel time for travelers (Li Haonan et al., 2019).

Most of the existing research is aimed at a single travel target, and the impact of different travel needs of most travelers on route decision-making has not been considered. In this paper, considering the characteristics of various modes of transportation, the travel demand of travelers and the variability of traffic network, with the goal of minimizing the generalized travel cost, a multi-mode path decision model is established based on dynamic programming theory. Through the analysis of practical examples, the multi-mode travel path of Nanjing is determined.

## 2. CONSTRUCTION OF MULTI-MODE PATH DECISION MODEL

### 2.1 Problem Description

With the acceleration of urbanization, people's travel choices are more diverse. The fundamental goal of the traveler in the travel path planning is the same. They all hope to travel from the origin to the destination with the least time and the lowest cost. There are multiple transferable stations between this distance. Travelers can choose buses, subways, bicycles and other ways through decision-making. It cannot be ignored that the transfer waiting time at the time of transfer needs to be considered within the total travel time. Therefore, travelers should make reasonable decisions to maximize travel efficiency.

### 2.2 Analysis of Traveler Decision-Making Behavior

In order to meet the needs of travel, the decision-making process of travelers generally includes the choice of travel path and travel mode. In the process of travel, according to the actual traffic information, the traveler will change the travel path or travel mode at the decision node. In general, travelers need to choose from the starting point, so the starting point can also be used as a decision-making node for travel. In addition, at the end of the trip, travelers can sort out and summarize the entire travel process to accumulate experience for future travel. Considering this factor, the paper also regards the travel destination as a decision node in the travel.

For travelers, they only need to choose at the decision node, so the actual travel road network can be transformed into a travel decision road network with only decision nodes. There must be more than two decision nodes in the multi-mode travel. Therefore, this is a multi-stage decision process, and the specific process can be represented by Figure 1. Based on this, this paper will use dynamic programming theory to model.

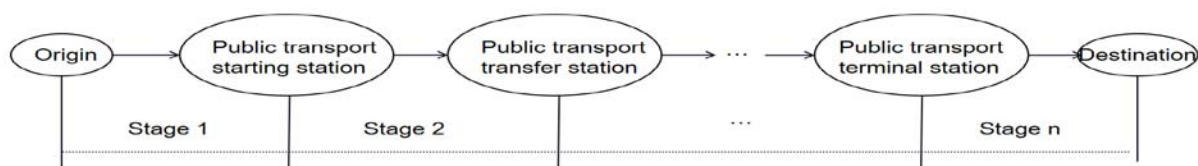


Figure 1: Multi-mode traffic travel decision-making process

## 2.3 Symbol Description

In order to facilitate the modeling description, the following symbols are defined:

$k = \{ 1, 2, \dots, n \}$  is the decision stage ;  $T = \{ w, b, B, m, t \}$  is a collection of transportation modes including walking, bicycle, bus and taxi ( where  $w$  refers to walking,  $b$  is bicycle,  $B$  is bus,  $m$  is subway,  $t$  is taxi ) ;  $U$  is the set of allowable decisions for each stage,  $u_k \in U$ ;  $VOT$  is the unit time value ;  $c_u ( k )$  is the generalized travel cost after the decision  $u_k$  in stage  $k$  ;  $t_u ( k )$  is the travel time cost after the decision  $u_k$  in stage  $k$  ;  $m_u ( k )$  is the travel cost after the decision  $u_k$  in stage  $k$  ;  $r_u ( k )$  is the travel time after the decision  $u_k$  in stage  $k$  ;  $r_{u, t} ( k )$  is the transportation time of this mode after the decision  $u_k$  in stage  $k$  ;  $r_{u, c} ( k )$  is the transfer time to this mode after the decision  $u_k$  in stage  $k$  ;  $r_{u, w} ( k )$  is the waiting time of this mode after the decision  $u_k$  in stage  $k$ .

## 2.4 Model Construction

### *2.4.1 Travel Time Conversion*

The generalized travel cost includes travel time cost and travel cost, but the dimension of time and cost is inconsistent, so it is necessary to convert travel time into travel time cost, which means that the travel time after the decision  $u_k$  is made in stage  $k$ . According to different decisions, its calculation formula is also different, as follows:

$$r_u(k) = r_{u,t}(k) \quad (1)$$

The formula (1) indicates that there is no change in the mode of transportation, or the change does not require transfer and waiting.

$$r_u(k) = r_{u,t}(k) + r_{u,w}(k) \quad (2)$$

The formula (2) indicates that there are transfer changes accompanied by waiting buses at this stage.

$$r_u(k) = r_{u,t}(k) + r_{u,w}(k) + r_{u,c}(k) \quad (3)$$

The formula (3) indicates that there is a transfer between the bus and the subway at this stage.

We use the formula (4) to calculate the time cost.

$$t_u(k) = VOT \times r_u(k) \quad (4)$$

In this paper, the wage method is used to calculate the unit time value  $VOT$  (yuan / hour), and the user's annual income value is selected to calculate the time value. The annual working time is calculated according to 2000 hours, that is:

$$VOT = \text{user 's annual income} / 2000 \text{ hours} \quad (5)$$

### *2.4.2 Multi-Objective Function Transformation*

For the calculation of generalized travel cost, the linear weighting method is used to express the sensitivity of different groups of people to time cost.

$$c_u(k) = \alpha \times t_u(k) + \beta \times m_u(k) \quad (6)$$

In the above formula,  $\alpha$  and  $\beta$  correspond to the weight coefficients of travel time cost and travel cost, and  $\alpha + \beta = 1, 0 \leq \alpha, \beta \leq 1$ .

### 2.4.3 Model Parameters and Formula Expression

The k-stage means that the ride interval between two nodes is divided into one stage; the state variable  $S_k$  refers to the node in the network that can be decided here; the decision variable  $u_k$  represents the path selected in stage k.

State transition equation:

$$S_{k+1} = u_k(S_k) \quad (7)$$

The phase indicator  $v_k$  is the generalized travel cost for each phase:

$$v_k(S_k, u_k) = c_u(k) \quad (8)$$

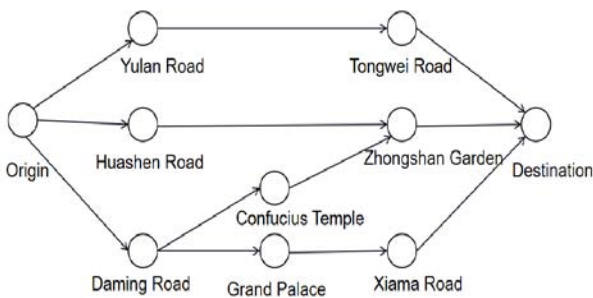
Optimal value function:

$$\begin{cases} f_k(s_k) = \min\{v_k(s_k, u_k) + f_{k+1}(s_{k+1})\} \\ f_{k+1}(s_{k+1}) = 0 \\ (k = 1, 2, \dots, n) \end{cases} \quad (9)$$

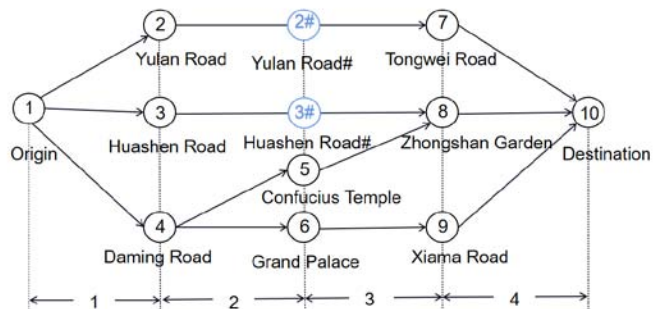
$f_k$  represents the minimum generalized travel cost in the state  $s_k$ , stage k to stage n.

## 3. EXAMPLE ANALYSIS

In order to verify the applicability of the dynamic programming model of multi-mode traffic travel, the paper selects a pair of starting and ending points in a certain area of Nanjing as a practical example for analysis. Among them, the starting point is Huashen Community, and the destination is the teaching center building of Nanjing Agricultural University. Combined with the actual situation, feasible bus and subway lines are selected, and four paths for travelers to choose can be obtained through integration. These paths are represented by specific transfer decision nodes, as shown in Figure 2.



**Figure 2: Directed path network composed of nodes**



**Figure 3: The node directed network after unified planning**

Between the multi-mode transportation networks, there are multiple modes of transportation between the two adjacent nodes of each path, so each path should be listed separately, and then the decision-making selection should be made according to the node division stage. In order to make a unified plan for the whole network, the path is now divided into a unified division, and the nodes are numbered to facilitate the representation. Because the number of nodes is inconsistent, the stage cannot be directly divided. Therefore, it is necessary to assume that there are two nodes in path one and path two,

Yulan Road # and Huashen Road #, in order to unify the division stage. The specific results are shown in Figure 3.

Due to the different applicable distances of different traffic modes, the time and cost required for different traffic modes between each node are obtained after screening the traffic modes that can be selected between each node of each path. The specific results are shown in the following table:

**Table 1: The optional transportation mode, time (min) and travel cost (yuan) of each section**

Ride Interval	Distance (km)	Optional Modes of Transport			
		Walk	Shared Bicycle	Bus	Subway
1-2	0.47	√、7.01、0	√、5.33、1.5	-	-
1-3	0.56	√、8.36、0	√、5.87、1.5	-	-
1-4	0.86	√、12.83、0	√、7.68、1.5	-	-
2-2#	0	-	-	-	-
3-3#	0	-	-	-	-
4-5	4.50	-	√、29.61、1.5	-	√、12.00、3
4-6	6.60	-	-	-	√、16.20、3
2#-7	10.20	-	-	√、36.63、2	-
3#-8	8.50	-	-	√、31.53、2	-
5-8	5.30	-	-	√、21.92、2	-
6-9	5.20	-	-	-	√、13.40、3
7-10	0.56	√、8.36、0	√、5.87、1.5	-	-
8-10	0.88	√、13.13、0	√、7.80、1.5	-	-
9-10	0.60	√、8.96、0	√、6.11、1.5	-	-

### 3.1 Parameter Calibration

The generalized travel cost includes travel time cost and travel cost, so it is necessary to convert travel time into travel time cost. According to Formula (4), combined with the per capita disposable income of all residents in Nanjing in 2019 released by Nanjing Bureau of Statistics, it can be concluded that the per capita unit time value VOT in Nanjing is CNY 28.82 per hour.

Since each traveler is an independent individual, the difference is reflected in individual travel choices. Because people with different incomes have different sensitivities to travel time costs and travel costs, the paper divides travelers into two categories: high-income people (time-sensitive) and low-income people (cost-sensitive). The following need to determine the weight coefficient of travel time cost and travel cost, that is, the value of  $\alpha$  and  $\beta$  in formula (6). Liu Mengqi et al. divided the sensitivity of different income groups (Liu Mengqi et al., 2017). This paper sets the travel time cost weight of high-income people as 0.62, the travel cost weight as 0.38, the travel time cost weight of low-income people as 0.37, and the travel cost weight as 0.63.

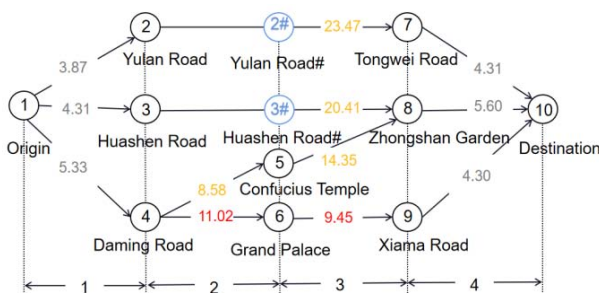
### 3.2 Decision Process and Outcome

According to the calibrated parameters and formulas (2-6), the generalized travel costs of high-income people and low-income people are calculated. The specific results are shown in the following table.

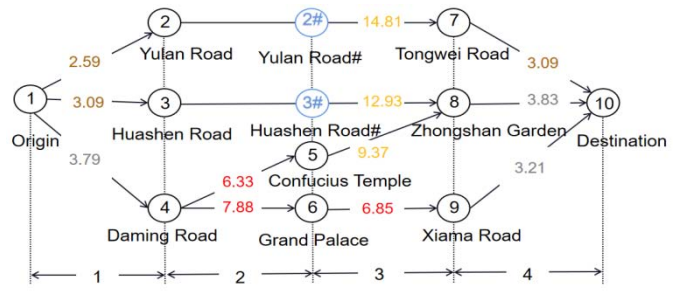
**Table 2: Generalized travel costs of different travel modes for high / low-income people**

Ride interval	Generalized Travel Cost (yuan)			
	Walk	Shared Bicycle	Bus	Subway
1-2	4.35/2.59	3.87/2.92	-	-
1-3	5.18/3.09	4.31/3.12	-	-
1-4	7.95/4.75	5.33/3.79	-	-
2-2#	-	-	-	-
3-3#	-	-	-	-
4-5	-	18.93/11.90	-	8.58/6.33
4-6	-	-	-	11.02/7.88
2#-7	-	-	23.47/14.81	-
3#-8	-	-	20.41/12.93	-
5-8	-	-	14.35/9.37	-
6-9	-	-	-	9.45/6.85
7-10	5.18/3.09	4.31/3.12	-	-
8-10	8.14/4.85	5.60/3.83	-	-
9-10	5.56/3.32	4.30/3.21	-	-

The lowest generalized travel cost corresponding to the travel mode in each interval is marked to the network diagram, and the path decision is made by using the dynamic programming theory to obtain the path of the lowest generalized travel cost.



**Figure 4: High-income group decision diagram**



**Figure 5: Low-income group decision diagram**

According to Figure 4, we can see that the network is divided into four stages, and the state variables  $s_1 = \{1\}$ ,  $s_2 = \{2,3,4\}$ ,  $s_3 = \{2 \#, 3 \#, 5,6\}$ ,  $s_4 = \{7,8,9\}$ . The state transition equation is  $s_{k+1} = u_k(s_k)$ . Using the reverse solution, the minimum generalized travel cost of high-income people is 30.10 yuan. The path node of the lowest generalized travel cost for high-income people is: 1-4-6-9-10. Travelers should choose Path 4 (Origin-Daming Road-Daxing Palace-Xiama Road-Destination) to complete the travel process. The corresponding travel mode is 1-4 to choose shared bicycles, 4-6-9 to choose subways, and 9-10 to continue to use shared bicycles. It is in line with the characteristics of high-income people with high time sensitivity.

Similarly, according to Figure 5, the minimum generalized travel cost of low-income people is 19.85 yuan. The path node that obtains the lowest generalized travel cost of low-income people is: 1-3-3 # -8-10, that is, path 1-3-8-10. Low-income travelers should choose path two (Origin-Huashen Road-Zhongshan Garden-Destination) to complete the travel process. The corresponding travel mode is 1-3 to choose walking, node 3 to choose buses, and 8-10 to use shared bicycles.

## 4. CONCLUSIONS

Under the background of increasingly diversified urban public transport modes, people's one trip often requires the coordination and cooperation of multiple modes of transportation to complete. This essay comprehensively measures the generalized travel cost from two aspects of travel time and travel cost. In the calculation process of travel time cost, the unit time value is used to transform, and the dynamic programming theory is used to deal with the variability of travel decision. A path decision model considering the lowest generalized travel cost is given. The applicability of the model is verified by practical example analysis. In fact, with the improvement of people's travel demand, more and more attention has been paid to other factors that affect travelers' travel decisions. Therefore, considering the multi-factor multi-mode traffic travel problem is also the next research direction.

## 5. ACKNOWLEDGEMENT

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