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A tour route planning model for tourism experience utility maximization

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Abstract

Tourism experience has great impact on the tourist satisfaction, and therefore, tourists pay more attention to the tourism experience utility of the tour. The present problem is how to plan the tour route to maximize tourism experience utility considering tourists' preference of attraction, time, and cost budgets. The utility function for the tourism experience, consisting of utilities of tourism activities and travel, was proposed. An optimization model for tour route planning was established with the objective function of the tourism experience utility. Then, the computational method to obtain the optimal solution was given, and the feasibility of the method was validated by an example of a tourism transportation network. Finally, sensitivity analyses were conducted by varying the parameters of the tourism experience utility. The results showed that the tourists' preference of attraction, degree of attention to travel time, and travel cost had great influence on the tour route planning. The tourists with high value of time tend to choose transportation mode with shorter travel times, and the tourism experience utility of the tourists with high value of time was higher than that of the tourists with low value of time.

Keywords

Tour route, tourist preference, tourism experience utility, transportation mode, routing planning

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Introduction

With improvement of living standards, tourism has become a new living fashion. The demand of tourism has shown diverse trends. Traditional tourism mode cannot well meet the needs of today's tourists. More and more tourists pursue physical experiences and satisfactions during the tour. In order to improve tourism experience, tourists plan the tour routes before traveling to unfamiliar scenic cities. With their preference and limit in time and money, tourists usually search for data from travel books, personal travel blogs, or friends to arrange tour routes.[1] The tour route planning is a time-consuming task. It is difficult to find out the attractions worth of visiting and to figure out the schedules of the tour. Therefore, tour route planning model is used to build high-quality tour routes for tourists.

The tour route planning problem (TRPP) has been studied by some researchers in the literature. An early work on tour planning was introduced by Butt and Cavalier.[2] In this work, they proposed a greedy construction procedure for solving the multiple tour

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maximum collection problem with a duration constraint. Then, TRPP is commonly seen as a variant of the orienteering problem (OP).[3] Bérubé et al.[4] dealt with a bi-objective traveling salesman problem with profits (TSPP) and provided the first exact solutions for TSPP instances. Vansteenwegen et al.[5,6] formulated TRPP as an integer programming problem. The goal of the problem was to provide a tour for tourist that maximizes profit within a time budget. However, the tourists' preferences on the same attractions are diverse; the profit may be determined according to tourists' preferences.[7] Abbaspour and Samadzadegan[8] discussed the itinerary planning based on tourists' preferences and restrictions of attractions. The multimodal shortest path subroutine was designed to generate a tour route for a tourist. Another study has been carried out by Rodríguez et al.[9] They developed a tourist support system (TSS) which considered tourists' conflicting objectives (e.g. distance traveled, activity costs, and activity utility), and a Tabu search procedure was given to solve the multi-objective problem. Brilhante et al.[10] presented TripBuilder which was a web tool helping tourists to build the personalized sightseeing tour. The point of interests (POIs) was chosen according to the profile of the tourist and the time budget of the tour. Then, the selected POIs were joined in an itinerary by a search algorithm addressing an instance of the traveling salesman problem. Other researchers have focused on tour route design for group members. Zhang and Xu[11] developed a corresponding model with multi-objective of group members. The itinerary could fulfill some constraints, such as the opening time of the attractions, tourists' wishes, and the optimal travel time. Kinoshita and Yokokishizawa[12] presented a tour route planning support system for multiple group members. With the Kansei database, the system recommended a set of attractions considering the preferences of group members. Gavalas et al.[13] modeled the tourist trip design problem as the time-dependent team OP. Taking into account the time available for sightseeing, the attractions that match tourists' preferences were selected, and travel times between attractions were calculated by the cluster-based heuristics. In summary, the target tour route should meet some criteria: variety of attractions, short travel time, and low tour cost.

The weakness of the previous research is that the attractions of the tour route were linked using a shortest path method. These work did not deal with the tourists' preferences, and the time and cost budget at the same time. And tourists may encounter some constraints during the tour planning, such as arriving at some attractions at some specified time, how to travel from one location to another, and how much time or money needed to spend at each attraction. To address this issue, the tour route optimization model based on maximizing tourism experience utility is developed in this study. The solution to the model is proposed and validated by numerical examples. Finally, conclusions and future work are given in the last section.

Tour route planning model

Building the model

Take Figure 1 as a scenario. In a scenic city, there are different types of attractions—nature parks, historical monuments, leisure entertainments, shopping markets, and so on. According to the restrictions as mentioned in section "Introduction," a tourist would plan a suitable tour route as shown in Figure 1(b).

With the problem presented in the article and the scenario of tour route planning as show in Figure 1, let $G = (V, E)$ be a tourism transportation network, where $V = \{v_1, v_2, \ldots, v_N\}$ is a set of nodes consisting of tour starting node (v_1), ending node (v_N), and attraction v_i $(i = 2, 3, \ldots, N-1)$. There is an available visiting

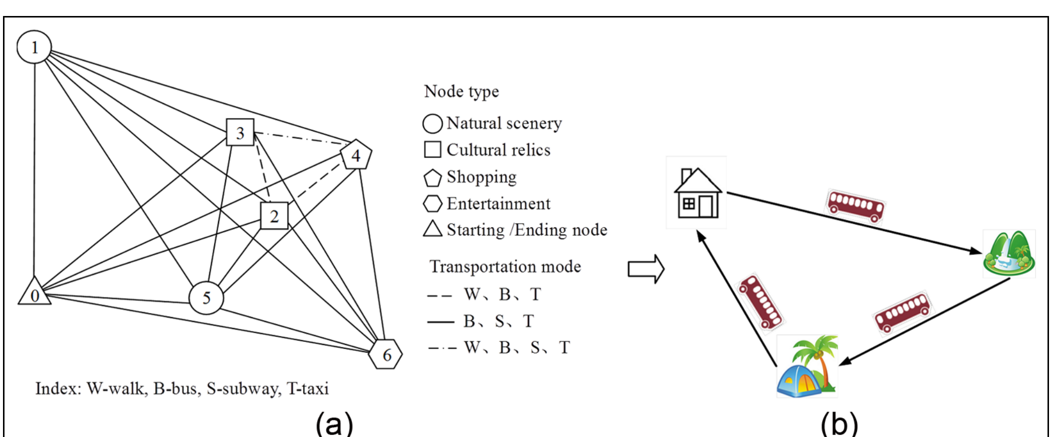

Figure 1. Scenario of tour route planning: (a) tourism transportation network and (b) sketch of the tour route.

time for each attraction, which is represented by an interval of opening time (t_{oi}) and closing time (t_{ci}). E is a set of edge, if v_i is adjacent with v_j, then there is one edge e_{ij} between them. In the graph, each edge e_{ij} has two attributes: travel time T_{ij}^k and travel cost C_{ij}^k. The travel time and travel cost among nodes v_i and v_j are dependent on which transportation mode the tourist chooses. A tourist also defines the start time t_{start}, the end time t_{end}, and the cost budget C for the tour. In the tour, the tourist starts the tour from the starting point v_1 at time t_{start} and arrives at attraction v_i at time t_{si} by the kth transportation mode. The tourist would spend a lot of time T_i^v and money C_i visiting the attraction. Then, the tourist departs at time t_{di} to the next attraction. After visiting many attractions, the tourist goes back to ending point v_N. Obviously, the tour route consists of attractions, their chronological sequences, and transportation mode for traveling from one node to another. Extra the time and the cost available for the tour should also be considered. Therefore, the tour route planning is to choose a set of tour elements meeting the constraints and tourists' preference of attraction, and determine the visiting order of them to make the tourism experience utility as large as possible.

Tourism experience obtained from the tour is important for tourists. Tourists would be more satisfied with higher experience in the tour. In addition to tourism experience in the attraction, tourists would have experience during transportation. Utility means the user's satisfaction to accept a service. Then, suppose the tourism experience utility consists of two parts, the utility associated with the travel and also that associated with tourism activities. The utility of the travel is assumed to have a linear function of the time and cost spent on transportation[14–16]

$$U_{ij}^k = \alpha_1 T_{ij}^k + \alpha_2 \varphi C_{ij}^k \tag{1}$$

where U_{ij}^k denotes the utility of the tourism travel from node i to node j by the kth transportation mode, and φ is a parameter that transfers the travel cost into travel time. Let $\varphi = 1/VOT$, where VOT is value of time of the tourist. It is clear that the smaller the VOT, the greater parameter φ is. α_1 and α_2 are effect parameters reflecting the sensitive degree of tourist to travel time or travel cost in the tour.

The utility of the tourism activity depends on tourists' preference. The utility of the tourism activity is assumed to be correlated with the attributes of the attraction, the time, and cost spent on the tourism activity in the attraction. The utility of the tourism activity may be expressed as follows

$$U_i^a = \beta_1 \tau A_i + \beta_2 T_i^v + \beta_3 \varphi C_i \tag{2}$$

where U_i^a is the utility of engaging in the tourism activity at the attraction i. A_i denotes the popularity of attraction i, and τ is a parameter that transfers the popularity into the time. β_1, β_2, and β_3 control the degree of sensitivity of tourist to the popularity, the duration, and the cost for visiting the attraction, respectively.

Hence, the objective is to maximize the tourism experience utility within the tour time and cost budget. The TRPP can be formulated as equations (3)–(15)

$$\max U = \max\left(\sum_{k=1}^{m}\sum_{i=1}^{n-1}\sum_{j=2}^{n} x_{ij}^k U_{ij}^k + \sum_{i=2}^{n-1}\delta_i U_i^a\right) \tag{3}$$

Subject to

$$\sum_{k=1}^{m}\sum_{j=2}^{n} x_{1j}^k = 1 \tag{4}$$

$$\sum_{k=1}^{m}\sum_{i=1}^{n-1} x_{in}^k = 1 \tag{5}$$

$$\sum_{k=1}^{m}\sum_{i=1}^{n}\sum_{j=1}^{n} x_{ij}^k = 1 \tag{6}$$

$$t_{d1} = t_{start} \tag{7}$$

$$t_{si} + T_i^v = t_{di} \tag{8}$$

$$t_{di} + T_{ij}^k = t_{sj} \tag{9}$$

$$\sum_{k=1}^{m}\sum_{i=1}^{n-1}\sum_{j=2}^{n} x_{ij}^k T_{ij}^k + \sum_{i=2}^{n-1}\delta_i (t_{di} - t_{si}) \le t_{end} - t_{start} \tag{10}$$

$$\sum_{k=1}^{m}\sum_{i=1}^{n-1}\sum_{j=2}^{n} x_{ij}^k C_{ij}^k + \sum_{i=2}^{n-1}\delta_i C_i \le C \tag{11}$$

$$t_{si} \ge t_{oi} \tag{12}$$

$$t_{di} \le t_{ci} \tag{13}$$

$$x_{ij}^k = \begin{cases} 1 & \text{if going from node } i \text{ to node } j \text{ by the } k \text{ transportation mode;} \\ 0 & \text{otherwise} \end{cases} \tag{14}$$

$$\delta_i = \begin{cases} 1 & \text{if node } i \text{ is selected;} \\ 0 & \text{otherwise} \end{cases} \tag{15}$$

The objective function (3) maximizes the tourism experience utility of the tourist. Constraints (4) and (5) ensure that the tour route starts from node 1 and ends at node n. Constraint (6) implies that no attractions are visited more than once, and tourists could only choose one transportation mode among two nodes. Constraint (7) is the tour start time constraint. Constraints (8) and

Table 1. Attribute parameters of attractions.

Number of attraction	Level of attraction	Tourist activity time (min)	Opening hours	Ticket (Yuan)
1	5	180	[6.18]	50
2	5	160	[8.17]	55
3	3	95	[9.20]	40
4	3	120	[10.23]	30
5	5	100	[8.20]	45
6	4	130	[8.22]	35

(9) calculate the departure time and the arrival time at each node. Constraints (10) and (11) guarantee that the time and cost budget of the tour are satisfied. Constraints (12) and (13) emphasize that each attraction is visited within its available visiting time interval. Constraints (14) and (15) define binary variables.

Solution algorithm

Because the TRPP is a combinatorial optimization problem, it is difficult to obtain the global optimal solution.[17] This article proposes a customized solution algorithm for the model, and it is described as follows:

Step 1. Initialize parameters—given t_{start}, t_{end}, C, the attributes of attractions and the properties of each edge. Let $k = 1$, v_1 is the source node and v_n is the destination node; so the initial route $PATH(1) = [v_1, v_n]$. $LABEL$ is a set of nodes to be checked in the route (if v_i has been in the route, its label is 1, otherwise is 0), $LABEL(1) = [1, 0, \ldots, 0, 1]$. AP is the schedule of the route. $MODE$ is the set of the selected transportation mode among two nodes in the route. Let $AP(1) = [\,]$, $MODE\,(1) = [\,]$.
Step 2. Processing the node—if $v_j \notin PATH(k)$, the node v_j is inserted into the candidate node list, CNL. If $CNL \notin \phi$, go to step 3, else go to step 7.
Step 3. Choose the transportation mode between v_i and v_j with which the utility of the travel is greatest—calculate the arrival time t_{sj} and departure time t_{dj} according to equations (8) and (9). If $t_{sj} \leq t_{oj}$ or $t_{dj} \geq t_{cj}$, delete v_j from CNL and update CNL. If $CNL \neq \phi$, go to step 4, else go to step 7.
Step 4. Insert the nodes of CNL into the route after the current node, respectively—these new routes are regarded as the set of candidate routes, CR.
Step 5. Check the total time and cost—calculate the total time and total cost of the route in CR, respectively. Delete the route unsatisfied constraint (10) or (11). If $CR \neq \phi$, go to step 6, else go to step 7.
Step 6. Let $k = k + 1$—with maximum utility, choose the route from the CR. Update $PATH(k + 1)$, $LABEL(k + 1)$, $MODE(k + 1)$ and $AP(k + 1)$. Repeat steps 2–5.
Step 7. Stop the process and output $PATH(k)$, $MODE(k)$, $AP(k)$.

Numerical example

Case description

An example graph shown in Figure 1(a) is given to evaluate the algorithm and the model. Figure 1(a) shows that node 0 is the source node and terminal node of the tour. There are six attractions in the tourism transportation network. Given the scenic city, the information about each attraction such as the level, ticket, opening, and closing time is collected from the city's tourism website. In addition, the stay time for each attraction is estimated based on tourists' travel histories of the attraction. The level of attraction, stay time for tourist activity, and tickets of six attractions are provided in Table 1.

In the tourism transportation network, there are four transportation modes: walk, bus, subway, and taxi. Between node 3 and node 4, the transportation modes are walk, bus, subway, and taxi. The transportation modes of the links (2–3, 2–4) are walk, bus, taxi, and that of the other links are bus, subway, taxi. Moreover, the tour route planning should consider the travel time and travel cost needed to travel from one node to another. To simplify the calculation, the travel time and travel cost for each link are estimated by querying Baidu maps. The values of travel time and travel cost of different transportation modes for each link are given in Table 2.

Optimized results

In this section, an example is provided to illustrate the practicability of the model: a tourist is going to visit some attractions departing at 8:30 and wants to return at 16:10 alone with the cost budget of 200 Yuan. Parameters in the proposed model are established based on the previous literature.[18] So let $\tau = 1.0$, $\varphi = 0.1$. α_1 and α_2 are set to be -0.5. Parameters β_1, β_2, β_3 are set to be 0.3, 0.4, -0.3, respectively. Again, assume that the cost of the tourist activity in the attraction is mostly for tickets. The popularity of

Table 2. Travel time and travel cost matrices for tourism transportation network.

Link	Travel time (min)				Travel cost (Yuan)			
	Walk	Bus	Subway	Taxi	Walk	Bus	Subway	Taxi
0–1	∞	110	64	52	∞	6	5	70
0–2	∞	60	40	25	∞	4	4	28
0–3	∞	54	36	20	∞	2	4	21
0–4	∞	80	45	38	∞	3	4	33
0–5	∞	40	30	24	∞	2	4	19
0–6	∞	90	40	36	∞	4	5	36
1–2	∞	97	70	45	∞	5	5	68
1–3	∞	90	50	30	∞	5	5	40
1–4	∞	120	80	56	∞	6	5	73
1–5	∞	114	70	57	∞	6	5	79
1–6	∞	174	83	67	∞	7	6	97
2–3	25	29	∞	11	0	2	∞	13
2–4	15	27	∞	8	0	2	∞	13
2–5	∞	30	18	15	∞	2	2	15
2–6	∞	50	40	22	∞	2	4	26
3–4	28	20	16	10	0	2	3	12
3–5	∞	34	21	18	∞	2	3	17
3–6	∞	70	50	40	∞	3	5	39
4–5	∞	40	25	25	∞	2	4	22
4–6	∞	65	44	30	∞	3	5	45
5–6	∞	56	37	21	∞	2	4	25

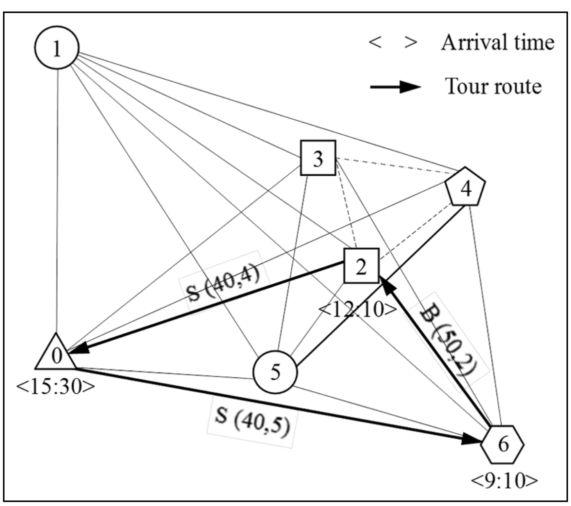

Figure 2. Schedule of the optimal tour route.

attractions is expressed by the level of attraction. The higher the level of attraction, the more popular the attraction is. Given these parameters, MATLAB is chosen to implement the proposed model using the solution algorithm in section "Solution algorithm." The detailed tour route is presented in Figure 2.

As shown in Figure 2, the optimal tour route consists of the attractions 2 and 6. Tourist could take the bus from the attraction 2 to 6, and the transportation modes for tourist traveling from starting point 0 to the attraction 6 and getting ending point from the attraction 2 are subway. The total cost of this tour is 101 Yuan. Tourist would take 420 min to the tour.

Parameters sensitivity analysis

To summarize, parameters α and β play an important role in the tour route optimization model to denote the choice criteria of transportation mode and tourists' preference of attraction, respectively. The value of φ has significant impacts on the optimization result. Thus, these parameters are varied to investigate how the optimization results vary with different model parameters.

With parameters α and φ kept constant, the optimal tour routes are obtained from the model with different values of β, as shown in Table 3. It can be seen that this formulation returns different tour routes based on different input parameters β_1, β_2, and β_3. If β_1 is very large, a tourist tends to select more popular attractions, and the tour route includes attractions 2 and 5 with high level. The travel time of the tour is short, but the cost of visiting the attractions 2 and 5 is high. Thus, the total tour cost of the tour route is higher than others. When $\beta_2 = 0.8$, it indicates that a tourist pays more attention to the stay time of tourism activity, so the optimal result is attractions 1 and 5. Long travel distance between nodes leads to high travel cost and long travel time, so the total tour time becomes longer. Table 3 also shows that the No. 3 tour route can meet the requirement of a tourist who is expected to choose cheaper attractions. Because of less cost in the attractions 2 and 5, the total tour cost of this route is lower. These results reveal that tourists' preference of attraction is an important factor in the tour route planning, and the method is able to find a tour route for different tourists based on tourists' demand.

Table 3. Optimal tour routes with different parameters β.

No.	β_1	β_2	β_3	Optimal tour route	Travel time (min)	Travel cost (Yuan)	Activity time (min)	Activity cost (Yuan)
1	0.8	0.1	−0.1	$0 \xrightarrow{B} 5 \xrightarrow{S} 2 \xrightarrow{S} 0$	98	8	260	100
2	0.1	0.8	−0.1	$0 \xrightarrow{S} 1 \xrightarrow{S} 5 \xrightarrow{B} 0$	174	12	280	95
3	0.1	0.1	−0.8	$0 \xrightarrow{S} 6 \xrightarrow{S} 4 \xrightarrow{S} 0$	129	14	250	65

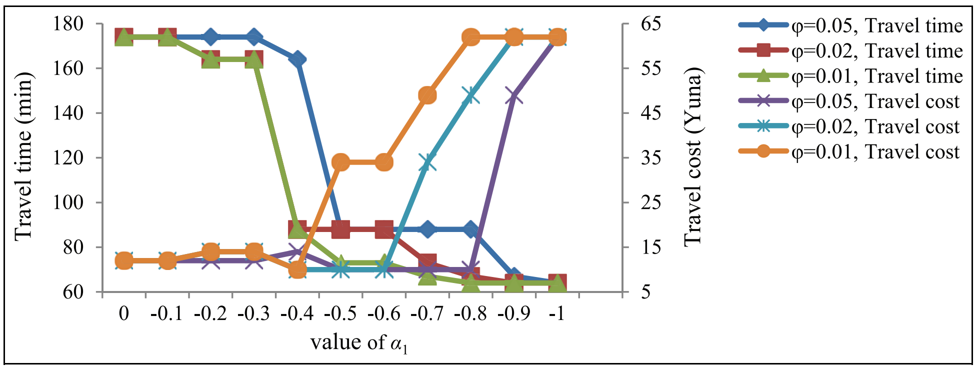

Figure 3. Travel time and travel cost of the tour route related to parameters α and φ.

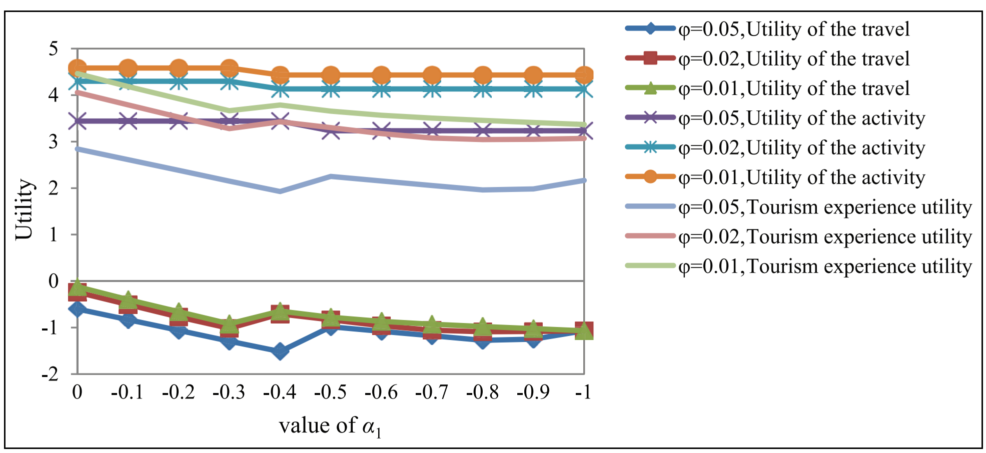

Figure 4. Tourism experience utility related to parameters α and φ.

Keeping the value of β fixed, parameter φ takes the values of 0.05, 0.02, and 0.01 for the three classes of tourists. Figure 3 shows the changes of total travel time and travel cost in the tour against parameters α and φ. By comparing different cases, the trend of the travel time varying with α_1 is similar to the trend with different values of φ. When α_1 is small, the travel time is the main choice criteria of transportation mode; a tourist tends to choose the transportation mode with shorter travel time. A tourist with high value of time prefers to take the taxi in the tour (i.e. when $\alpha_1 = 0.7$ and $\varphi = 0.01$, the optimal tour route is $0 \xrightarrow{T} 2 \xrightarrow{S} 5 \xrightarrow{T} 0$). And a tourist with low value of time is more inclined to take the subway (i.e. when $\alpha_1 = 0.7$ and $\varphi = 0.05$, the optimal tour route is $0 \xrightarrow{T} 2 \xrightarrow{S} 5 \xrightarrow{S} 0$). Hence, larger amount of travel cost is generated for tourists with high value of time. When α_1 is very large, the travel cost is the main factor affecting the choice of transportation mode. As shown in Figure 3, there are no significant differences in travel time and travel cost between tourists with high value of time and those with low value of time. This highlights the fact that it is similar to the two kinds of tourists in the choice of transportation mode with shorter considered travel time. Figure 4 provides the values of utility obtained from the optimal results for different values of parameters α and φ. When the value of α_1 varies, it can be clearly noticed that tourists with high value of time have higher tourism experience utility than tourists with low value of time. It is because tourists with high value of time are less sensitive to travel cost and choose the transportation mode that takes shorter travel time.

Therefore, tourists with high value of time experience less disutility than tourists with low value of time in travel. Similarly, low level of sensitivity to cost will lead to the higher utility of the tourism activity for tourists with high value of time in attractions. In summary, parameter α has important influence on tourists' route planning and their tourism experience utility. Travel experience is the second factor affecting the tourist route planning. Understanding the tourists' behavior characteristics with changes of α is conducive to the traffic management and improvement of the tourists' travel experience.

Conclusion

The tour route planning model based on maximizing the tourists' tourism experience utility was proposed in the article. In this model, the time, cost, and the attribute of attractions were considered. The customized algorithm to solve the optimization problem was designed, and the model validity was verified through a numerical example. The experimental results show that tourists' preference of attraction has an important effect on the tour route planning, and the attentions to the travel time and travel cost are positively correlated with the result of the tour route planning.

The aim of tour route planning is to design high-quality tour route for tourists. Apparently, the plan generally divides the tour route into two main parts: travel and tourism activity. And tourists may have different emphases for their tour routes. The above analysis shows that the tourists' preference of attraction, transportation mode, attributes of attractions, time, and cost budget should be considered in the tour route planning. Only this way can provide a tour route to meet tourists' demand.

In this article, tourism transportation network is constructed based on the constant travel time. In fact, traffic has dramatic impact on the travel time. It is important to refine the tourists' transportation mode choice behavior in future research. Additionally, some popular attractions will be crowded during peak tour seasons. The overcrowding will affect the stay time and lead to a poor tourism experience for tourists. Therefore, how to introduce this factor into the tour route planning model should be discussed in the future.

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