Tour route planning problem with consideration of the attraction congestion

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Abstract. Tourism experience is related to attraction congestion. A concept of congestion degree was proposed to describe the congestion level of attraction and the tourism experience utility was proposed. The optimal model of the tour route planning was established with maximizing tourism experience utility. And ant colony algorithm was developed to solve the mode. The tourism transport network was designed to verify the model. The results showed that tourism experience utility of tourist with low sensitivity to congestion was higher than that of tourist with high sensitivity to congestion. As tend to choose the shorter time traffic, tourist would have lower tourism experience utility.

Key words. tour route, congestion degree, taper constants, tourism experience utility, ant colony algorithm.

1. Introduction

Tourism activities have gradually become an important part of people's social activities. Due to the popularity of attractions, information guidance and other factors, large tourist quantity and uneven distribution of tourists in time and space in some of the spots occur at times, resulting in crowding in the attraction. Tourists want to plan tour routes, they need to consider the personal preference, attraction congestion, tour time and cost budget.

For the personalized tour route planning, scholars have done many studies.

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Choudhury et al.[1] planned a tour route to meet the time budget for self-help tourists in the case of a given route and end spot. Gionis et al.[2] extended the study and proposed a tour route planning model based on the order of scenic spots. Brilhante et al.[3] defined the tour route planning as a generalized maximum coverage problem, taking into account the popularity of the attractions and the preference of the tourists. Gavalas et al.[4] discussed the solution of personalized tour route planning. Brilhante et al.[5] establish a personalized tour route recommendation system. Abbaspour et al.[6] studied the issue of time-dependent tour route planning, taking into account factors such as tourist preference, attractions service time and transportation. The tourism congestion has also received attentions among researchers.[7] They pointed out that tour congestion has a impact on the tourist experience.

2. Tour Route Planning Model

The tourism transportation network is showed in Fig.1. $G = (V, E)$ is established. $V = \{v_1, v_2, \cdots, v_n\}$ is a set of nodes consists of the starting point (v_1),end point (v_n) and attractions $v_i (i = 2, 3, \ldots, n-1)$. The opening hours of attractions are $[t_{open,i}, t_{close,i}]$.$Cap_i$ is the capacity of the attraction. E is the set of edges. The travel time and travel cost among nodes by transportation mode k are $T^k_{travel,ij}$ and $C^k_{travel,ij}$ respectively. Tourists depart at $t_{start}$and arrive at$t_{arrive,i}$. If the attraction $i$is not opened, they need to wait $T_{wait,i}$. The average duration and cost for visiting the attraction v_i are $T^0_{duration,i}$, $C_{activity,i}$. After the tour, tourist may have a number of attractions to visit, and is expected to return at t_{end}. Assuming

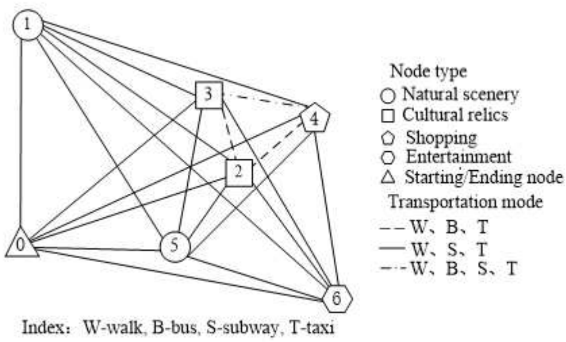

Fig. 1. Tourism transportation network

tourism experience utility consist of the tourism activity utility and travel utility. The travel utility is:

$$U^k_{travel,ij} = \alpha_1 T^k_{travel,ij} + \alpha_2 \varphi C^k_{travel,ij} \tag{1}$$

Where α_1, $\alpha_2$are the tourists' preferences to travel time and travel cost; Let $\varphi = 1/VOT$, VOT is the value of time.

Tourists have an acceptable number of tourists at the attraction.[8] The number of tourists at different times is:

$$Num_i(t_i) = \gamma_i \cdot \exp\left(\frac{-((t_i - t_{open,i}) - \mu_i)^2}{2 \cdot \omega_i^2}\right) \tag{2}$$

Whereγ_i,$\mu_i$and ω_i are the basic parameters for the tourist flow.

According to the number of tourists and attraction capacity, the congestion degree of attraction i moment t is:

$$Y_i(t) = \begin{cases} 0, & \text{if } \frac{Num_i(t)}{Cap_i} < 0.5 \\ e^{0.5(Num_i(t)/Cap_i - 0.5)} - 1, & \text{otherwise} \end{cases} , \forall t_i \in [t_{open,i}, t_{close,i}] \tag{3}$$

The duration of tourism activity in the attraction is related to the congestion degree when tourist starts touring the attraction.[9] The duration for visiting attraction is:

$$T_{duration,i}(t) = T^0_{duration,i} \cdot [1 + \alpha_0 \cdot Y_i(t)^{\beta_0}] \tag{4}$$

During the tour, tourists usually prefer to arrive at a certain time, and define the desired arrival time$t^*_{arrive,i} \in [t_{open,i}, t_{close,i} - T_{duration,i}]$. Tourist is fully satisfied when arriving within that time. In addition to the expected arrival time, the tolerable arrival time $[t_{open,i} - \Delta T, t_{close,i} - T_{duration,i} + \Delta T]$ should also be included. Negative utility $U_{SD,i}(t_{arrive,i})$ generated by delay in the activities of attraction i can be expressed as:

$$U_{SD,i}(t_{arrive,i}) = \begin{cases} M, & t_{arrive,i} < t_{open,i} - \Delta T \\ \eta_{early}(t_{open,i} - t_{arrive,i}), & t_{open,i} - \Delta T \leq t_{arrive,i} < t_{open,i} \\ 0, & t_{open,i} \leq t_{arrive,i} \leq t_{close,i} - T_{duration,i} \\ \eta_{late}(t_{arrive,i} - (t_{close,i} - T_{duration,i})), & t_{close,i} - T_{duration,i} + \Delta T \\ M, & t_{arrive,i}\, t_{close,i} - T_{duration,i} + \Delta T \end{cases} \tag{5}$$

Where η_{early},η_{late} are the unit time delay penalty factors for the early and late arrival; ΔT is the tolerable arrival time difference; M is the penalty constant that is large enough to violate the tolerable arrival time.

Based on the above analysis, the function of the tourism activity utility is defined as:

$$U_{activity,i} = \frac{\beta_1 A_i + \beta_2 \ln(T_{duration,i})}{\exp(\beta_3 Y_i(t_{arrive,i}) + \beta_4 C_{activity,i})} + U_{SD,i}(t_{arrive,i}) \tag{6}$$

Where A_i is the attractiveness of attraction;β_1 is the balance coefficient of the attractiveness of the attraction to tourists;β_2 is the balance coefficient of the congestion;β_3 is the balance coefficient of the duration for visiting attraction;β_4 is the balance coefficient of the cost.

In summary, the tour route planning problem corresponds to a mathematical model:

$$\max U = \max(\sum_{k=1}^{m}\sum_{i=1}^{n-1}\sum_{j=2}^{n} x_{ij}^{k} U_{travel,ij}^{k} + \sum_{i=2}^{n-1} y_i U_{activity,i}) \tag{7}$$

$$\sum_{k=1}^{m}\sum_{j=2}^{n} x_{1j}^{k} = 1 \tag{8}$$

$$\sum_{k=1}^{m}\sum_{i=1}^{n-1} x_{in}^{k} = 1 \tag{9}$$

$$\sum_{k=1}^{m}\sum_{i=1}^{n}\sum_{j=1}^{n} x_{ij}^{k} = 1 \tag{10}$$

$$T_{wait,i} = \max\left[(t_{open,i} - t_{arrive,i}), 0\right] \tag{11}$$

$$\sum_{k=1}^{m}\sum_{j=2}^{n}(t_{arrive,i} + T_{wait,i} + T_{duration,i} + T_{travel,ij})x_{ij}^{k} = t_{arrive,j} \tag{12}$$

$$t_{open,i} - \Delta T \le t_{arrive,i} \le t_{close,i} - T_{duration,i} + \Delta T \tag{13}$$

$$t_{arrvie,1} = t_{start} \tag{14}$$

$$t_{arrive,n} \le t_{end} \tag{15}$$

$$\sum_{k=1}^{m}\sum_{i=1}^{n-1}\sum_{j=2}^{n} x_{ij}^{k} C_{travel,ij}^{k} + \sum_{i=2}^{n-1} y_i C_{activity,i} \le C \tag{16}$$

$$x_{ij}^{k} = \begin{cases} 1 & \text{if going from node } i \text{ to node } j \text{ by the } k \text{ transportation mode;} \\ 0 & \text{otherwise} \end{cases} \tag{17}$$

$$y_i = \begin{cases} 1 & \text{if node } i \text{ is selected;} \\ 0 & \text{otherwise} \end{cases} \tag{18}$$

Where formulas(8)-(9) ensure that tourists start from the node 1 and return to the node n; formula(10) ensures that tourists can only choose one transportation mode in each edge; formulas(11)-(12) calculate the waiting time and the arrival time; formulas(13)-(16) are the tour time and cost budget constraints; formulas (17)-(18) are decision variables.

3. Solution Algorithm

Tour route planning is NP hard problem. The ant colony algorithm is applied to solve the mode.[10]

3.1. Node selection strategy

An ant starts from the starting point $l(l = 1, 2, \cdots s)$ and seeks for a feasible route to the end point. The initial solution of the ant takes $[(v_1, t_{start}), (v_n, t_{end})]$. The set $allowed_l$ contains all the currently accessible attractions that satisfy the constraints. Select nodes from $allowed_l$ as follows: randomly generate variable q in (0,1), when $q \leq q_0$, select node according to formula (19); when $q > q_0$, select according to formula(20).

$$j = \arg \max_{l \in allowed_l} (\tau_{il})^{\lambda} (\eta_{il})^{\sigma} \tag{19}$$

$$P_{ij}^{l} = \begin{cases} \frac{\tau_{ij}^{\lambda} \cdot \eta_{ij}^{\sigma}}{\sum_{l \in allow_l} \tau_{il}^{\lambda} \cdot \eta_{il}^{\sigma}}, & l \in allowed_l \\ 0, & l \notin allowed_l \end{cases} \tag{20}$$

Where τ_{ij} is the pheromone on the route between nodes i and j; η_{ij} is the heuristic information function relating to the route between nodes i and j; λ, σ are the pheromone factor and heuristic factor.

3.2. Solving steps

According to the above ideas, the solving algorithm of the model is as follows:

Step 1: Read the information of tourism traffic network and initialization algorithm parameters.

Step 2: Place the ant for search. s ants will be placed at the starting point 0 and search by ants.

Step 3: Select the next node. Read the current node number of the ant, select transport means by the principle of maximizing travel utility, and press node selection strategy to select the next node.

Step 4: Make judgment at the end of the search. Calculate the travel time and cost of the ant travel route, if the travel time and cost exceed budget, return to Step 2. If not, return to Step 3.

Step 5: Update the pheromone on the route.

Step 6: Determine whether the iteration is terminated, if the number of iterations does not reach the maximum number $iter$, return to Step 2, otherwise go to Step 7.

Step 7: Result output. The program terminates and outputs the best result.

4. Numerical example

4.1. Basic data

Suppose that the tourism traffic network in the city shown in Fig. 1. And the attribute parameters of attraction are showed in Table 1. The travel time and travel cost among nodes are listed in Table 2.

Table 1. Attribute parameters of attraction

Number of attraction	Level of attraction	Average duration for visiting attraction (min)	Opening hours	Ticket (Yuan)	Capacity
1	5	180	[6,18]	50	1000
2	5	160	[8,17]	55	1200
3	3	95	[9,20]	40	800
4	3	120	[10,23]	30	500
5	5	100	[8,20]	45	600
6	4	130	[8,22]	35	1000

Table 2. Travel time and travel cost matrices for tourist transport network

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

4.2. Settings of input parameters

The tourist sets off at 8:30, the expected return time is 17:30, and the tour cost budget is 250 Yuan. The values of tourism experience utility function parameters are $\alpha_0 = 1$, $\beta_0 = 0.8$, $\varphi = 0.02$, $\alpha_1 = \alpha_2 = -0.5$, $\beta_1 = 0.2$, $\beta_2 = 0.3$, $\beta_3 = 0.1$, $\beta_4 = 0.002$, $\Delta T = 5$, $\eta_{early} = -0.15$, $\eta_{late} = -0.5$; the attractiveness of the attraction is expressed by the level of attraction, and the cost of tourism activities in the attraction is only the ticket. The parameters related to the tourist flow are shown in Table 3. And set the algorithm parameters $\lambda = 1$, $\sigma = 5$, $\rho = 0.1$, $s = 50$, $iter = 100$, $q_0 = 0.1$, $\tau_0 = 0.1$.

Table 3. Value of parameters related to the tourist flow

Attraction	1	2	3	4	5	6
γ_i	700	900	500	300	400	700
μ_i	360	180	280	180	360	460
ω_i	180	100	140	160	300	120

4.3. Result analysis

With the initial conditions, the model is solved by the solution algorithm. The optimal route and the tourism experience utility is 2.02. Under the same parameters, analyze the effect of different β values on the results, as shown in Table 4.

Table 4. Optimal tour routes with different parameters β

No.	β_1	β_2	β_3	β_4	Tour time (min)	Tour cost (Yuan)	Congestion degree of the route	Tourism experience utility
1	0.7	0.3	0.1	0.002	536	150	0.06	8.28
2	0.7	0.3	0.8	0.002	537	151	0	8.18

Index: Congestion degree of the route is the sum of the congestion degree of scenic spots along the route.

As shown in Table 4, when β_3=0.8, the tourist is more sensitive to the attraction congestion, the result is route 2. Although the attractions of route 1 and 2 are the same, the tour order is different, so is the congestion degree of attraction, which also shows that tourists can change the attraction tour order to avoid crowding. Although the congestion degree of route 1 is higher than route 2, its travel time and cost are less than route 2, the trip also has a lower negative effect. Thus, the tourism experience utility of route 1 is higher than that of route 2.

To verify the effect of the travel utility function parameter variation on the experimental results, change the value of parameterα, compare the optimization results of β_3 taking 0.2 and 0.8, as shown in Fig.2-Fig.4. Fig.2 shows that when α_1 is set be

0 to 0.8, the route congestion degree of tourist with high sensitivity to congestion is less than that of tourist with low sensitivity to congestion. Due to congestion, the tourism activity time and travel time of tourist with low sensitivity to congestion are longer. When choosing the transportation modes with shorter travel time, the two types of tourists both have a higher congestion degree of the route, and there is no significant difference in travel time. Fig. 3 shows that there are no significant differences in the tour, travel and activity cost of the two types of tourists at differentα_1. When α_1=-0.2, β_3=0.8, tourists choose the transportation modes with less travel cost. When α_1=-0.8, β_3=0.8, tourists choose the transportation modes with shorter travel time, the cost of travel and tourism activity are higher, so the tour cost is higher. It can be seen that the choice of transportation has a significant impact on tour cost. Fig.4 shows that the tourism experience utility of the two types of tourists decreases with the decreasing ofα_1. When $\alpha_1$is small, tourists tend to choose transportation modes with shorter travel time, the higher travel cost, the greater the negative effects, and the tourism experience utility declines. This shows that tourists could not get better tourism experience by blindly pursuing shorter travel time. In the same selection criteria of transportation modes, the attraction congestion degree has a great impact on the tourism activity utility of the tourist with high sensitivity to congestion. Thus, the tourism activity utility of tourist with high sensitivity to congestion is lower than that of the tourist with low sensitivity to congestion, and the latter can get higher tourism experience utility.

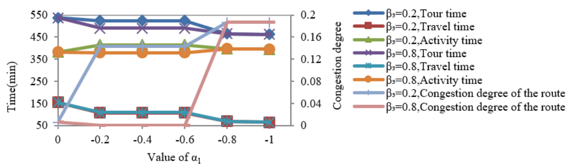

Fig. 2. Time and congestion degree of the route related to parameters $\alpha_1$andβ_3

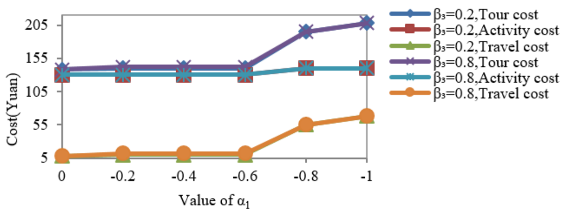

Fig. 3. Cost of tour route related to parameters $\alpha_1$andβ_3

Due to the departure time of tourists has a certain impact on the arriving time of attraction. Under the same parameters, the tourist's tour time budget is set to 7h. As shown in Fig.5, when the tourist departs early, for example at 7:30,reaching the attraction at 8:10 and 11:08. When the tourist reaches attraction 2, no congestion appeared in the attraction. And the congestion degree of attraction 5 is also less. Thus, the congestion degree of route is lower, and the tourism activity utility is higher. When departure time is 9:00, the tour route is the same as that of 7:30, but

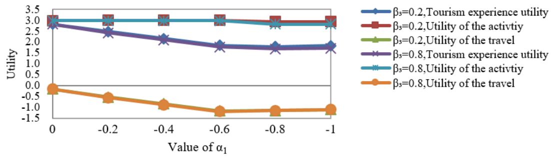

Fig. 4. Tourism experience utility related to parameters $\alpha_1$andβ_3

the arriving time is 9:40 and 12:46. Tourists are crowded at the attractions, and the tourism activity utility also will decline. It is obvious that tourists can avoid the attraction congestion and get higher tourism activity utility by setting a reasonable departure time.

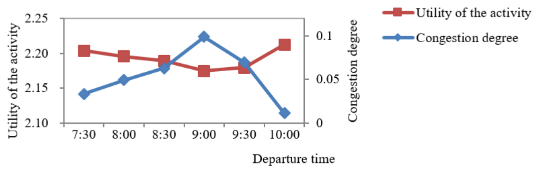

Fig. 5. The relationship between utility of the tourism activity and congestion degree with departure time

5. Conclusions

This paper constructed the function of tourism experience utility considering travel time, travel cost, attraction attributes, and congestion of attraction. With maximizing the tourism experience utility, the tour route planning model was established and ant colony algorithm was used to solve the model. Through analysis, we can see that the attraction congestion has a great influence on tourism experience utility and the duration for visiting attraction, which is an important factor affecting the tour route planning. There is a significant difference in the duration for visiting attraction between the tourists with low sensitivity to attraction congestion and that with high sensitivity to attraction congestion. The tourism experience utility gained by the tourists with high sensitivity to attraction congestion is less than that of the tourists with low sensitivity to attraction congestion. The change in the selection criteria of transportation modes will affect the result of tour route planning, and if the tourists tend to choose transportation modes with shorter travel time, they may not get better tourism experience utility. During the tour, tourists can avoid the attraction congestion by changing the tour order of attractions or departure time, which requires the administrative department to release congestion information so that tourists can plan the tour route in advance.

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