Travel Route Optimization Based on 0-1 Integer Programming

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Abstract. This paper carries out the research on tourism route optimization based on 0-1 integer programming, aiming to provide scientific planning solutions for diversified tourism needs. Firstly, a single-objective optimization model is constructed to obtain the optimal route and time cost for visiting major cities in the shortest time. Secondly, for the analysis of the travel plan to get the most "A-star" experience in three weeks, the single-objective planning model is used first, and then the multi-objective planning model is optimized by considering the influence of rest time on the travel experience, setting different weights, and then solving the problem again to get a more reasonable travel plan. Finally, the single-objective planning model is used to obtain the optimal route and the maximum number of attractions for the demand of visiting the most attractions. The model proposed in this study effectively responds to specific tourism situations, provides a generalized solution for tourism planning, and demonstrates stability in response to budget and cost changes.

Keywords: Travel route optimization; 0-1 integer planning; single-objective planning; multi-objective planning.

1. Introduction

In the present time of increasing tourism demand, tourism route optimization is crucial for enhancing tourism experience and rational use of resources[1]. This paper synthesizes the use of computer-related algorithms to carry out in-depth research around self-driving tour routes[2]. For the self-driving tour planning, the research uses model algorithms such as 0-1 integer planning[3], single-objective planning and multi-objective planning[4]. First, for the case of touring all cities and returning with minimum cost, a 0-1 integer planning model is constructed with time efficiency as the objective function. Second, in the route planning for getting the most "A-star" experiences in 21 days, a multi-objective optimization model is constructed and optimized as a multi-objective planning model by combining the constraints. Finally, a 0-1 integer planning optimization model is built for visiting the most attractions under a limited budget, with whether to go to the next city as the decision variable. By using these algorithmic models comprehensively, this paper effectively responds to the key situations in tourism route planning and provides a scientific and practical method for tourism route optimization[5].

2. Data Analysis

Fig. 1 is composed of a nonempty vertex set V and an edge set E, denoted $G = (V, E)$, a finite set of nonempty points in the graph denoted $V(G)$, and a set of edges between vertices on the way denoted $E(G)$. The graph (G) satisfies the following properties: A. There are no repeated edges, B. There are no edges from vertices to themselves, as can be seen from the graph. There are 49 undirected edges.

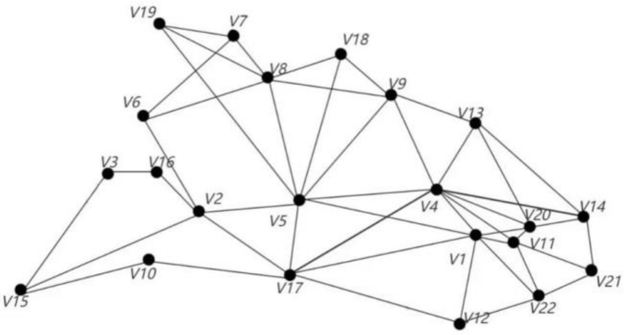

Fig. 1 Undirected Graph Representation of 22 Cities

Among them.

$$V(G)=\begin{Bmatrix}V_1,V_2,V_3,V_4,V_5,V_6,V_7,V_8,\\ V_9,V_{10},V_{11},V_{12},V_{13},V_{14},V_{15},\\ V_{16},V_{17},V_{18},V_{19},V_{20},V_{21},V_{22}\end{Bmatrix} \tag{1}$$

Combine the scenic categories to make the corresponding Fig. 2.

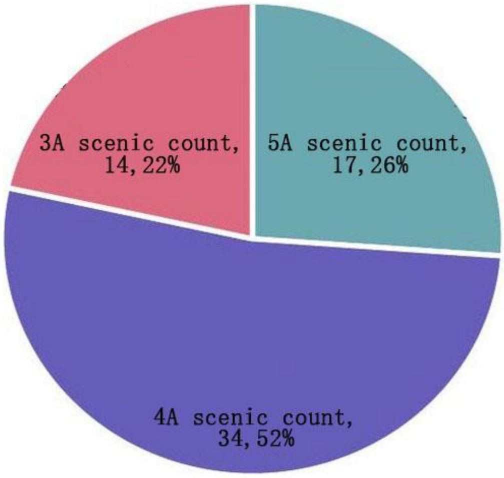

Fig. 2 Simple representation of scenic category and number of scenic spots

The final analysis shows that Wuhan has the largest number of 5A scenic spots, Huanggang and Shennongjia have the largest number of 4A scenic spots, and Wufeng and Xiaogan have the largest number of 3A scenic spots by the percentage of scenic spot types in each region.

The analysis of the transit time of each city and the types of scenic spots in each region concludes that Wuhan $(V2)$ is the most suitable city to be used as a transit city, Suizhou and Huanggang have the advantage in transit time but have no strengths in the types of scenic spots, whereas Yichang has obvious transit advantages in the western region, and its geographic location and the types of scenic spots in the western region are more advantageous than the other cities.

3. Route Planning Based on Minimizing the Total Time Cost of the Tour

3.1. Single-Objective Optimization Model Building

The objective of the study in this section is to utilize the shortest time to complete the tour of each city and return to Wuhan. Vertex v_1 represents the origin and destination, i.e., Wuhan, and vertices v_i, $i=2,3,\ldots,22$ represent the remaining 21 cities, and the weights of the edges from vertices v_i to v_j are denoted by e_{ij}, and when there is no edge between the two vertices, the corresponding weights are denoted by M (a sufficiently large positive real number), where $e_{ii}=M, i=1,2,\ldots,22$. Then the decision variables are e_{ij}, x_{ij}.

Where:

$$x_{ij}=\begin{cases}1, From\ city\ v_i\ Through\ city\ v_j\\0, Not\ from\ city\ v_i\ Through\ city\ v_j\end{cases} \tag{2}$$

The time cost of traveling from city i to city j is a multidimensional and comprehensive consideration, which not only includes the actual traveling time, but also deeply reflects the intensity of willingness to travel to the city and whether to choose to visit the city repeatedly. e_{ij} is the time of a single trip from city i to city j and $e_{ij}=d_{ij}/v, v=80$ km/h.
From this it can be determined that the objective function is:

$$f=\sum_{i=1}^{22}\sum_{j=1}^{22} e_{ij} * x_{ij} \tag{3}$$

The corresponding constraints can be obtained:

(1) For any city, are uniquely passed through and out of, and cannot pass through itself. This establishes the flow conservation constraint:

$$\sum_{i=1}^{22} x_{ij}=1, \forall j \neq i, (j=1,2,\dots,22) \tag{4}$$

Also consider the existence of the probability of repeated entry into the same city, and then add constraints.

(2) Limit the range of values of u_j:

$$u_1=0, 1 \leq u_i \leq 21, i=2,3,\dots,22. \tag{5}$$

(3) Each edge does not constitute a sub-loop, i.e:

$$u_i-u_j+22x_{ij} \leq 21, i=1,2,\dots,22, j=2,3,\dots,22. \tag{6}$$

3.2. Solving the Model

In this section, based on the 0-1 integer programming, the interior point method is used to approach the optimal solution region step by step along the gradient direction of the objective function through the constraints. By searching for the optimal solution in the “interior” of the feasible domain, the method avoids the complexity that may be brought by the boundary search, and thus can converge to the optimal solution much faster in many cases.

The vertex v_1 satisfies the constraint that it lies in the strict interior of the 22 passable cities. The value of the objective function is reduced in each iteration. As the iteration progresses, the effect of the obstacle term decreases to meet a certain convergence criterion, the iteration stops and the current point is considered to be the near-optimal solution. The optimal solution is obtained at this point.

The cost of time required to travel along the optimal path is explored and finally the time under the current given conditions is derived as in table 1.

Table 1. Details of Time Cost

Road	Time cost
$V_1 \rightarrow V_4$	0.7625 h
$V_4 \rightarrow V_9$	1.4500 h
$V_9 \rightarrow V_{18}$	1.2500 h
$V_{18} \rightarrow V_5$	1.9375 h
$V_5 \rightarrow V_{17}$	1.1375 h
$V_{17} \rightarrow V_{10}$	2.1875 h
$V_{10} \rightarrow V_{15}$	2.2500 h
$V_{15} \rightarrow V_3$	2.3750 h
$V_3 \rightarrow V_{16}$	1.7500 h
$V_{16} \rightarrow V_2$	0.5875 h
$V_2 \rightarrow V_6$	3.0750 h
$V_6 \rightarrow V_7$	2.4000 h
$V_7 \rightarrow V_{19}$	1.3000 h
$V_{19} \rightarrow V_8$	2.1250 h
$V_8 \rightarrow V_{11}$	1.9375 h
$V_{11} \rightarrow V_{20}$	0.2000 h
$V_{20} \rightarrow V_{13}$	1.5000 h
$V_{13} \rightarrow V_{14}$	2.0250 h
$V_{21} \rightarrow V_{22}$	0.8375 h
$V_{22} \rightarrow V_{12}$	1.2500 h
$V_{12} \rightarrow V_1$	1.2750 h

Total cost 34.5375 h.

4. Optimization of Tourism Routes with the Most "A-Star" Experiences

4.1. Single Goal Model

This section restricts play time to 21 days, requiring a maximum of "A-star" experiences within those 21 days. The time spent in transit and the time spent at the attractions make up the time spent in the 21 days. Therefore, the decision variables to consider whether to travel to the next city on the tour and whether to visit the attractions are: x_{ij}, z_{jk}, A_{jk}.
Where:

$$z_{jk} = \begin{cases} 1, & \text{Playing " k" attractions in " j" places} \\ 0, & \text{No " k ' sightseeing in ' j " land} \end{cases}, k \in [1,6], k \in Z \tag{7}$$

A_{jk} denotes the number of stars corresponding to the kth attraction in city j. The decision variable directly affects the playing time of the attraction. Then the objective function is:

$$a = \sum_{i=1}^{22} \sum_{k=1}^{6} z_{ik} * A_{ik}, i, k \in Z \tag{8}$$

The constraints can be obtained:

(1) The time that can be used in 21 days is only 336h, and the time to visit the k attractions located in i place is T_{ik}, so the total time constraint is obtained:

$$\sum_{i=1}^{22} \sum_{j=1}^{22} e_{ij} * x_{ij} + \sum_{i=1}^{22} \sum_{j=1}^{22} z_{ik} * T_{ik} \leq 336, i, j, k \in Z, \tag{9}$$

Where:

$$x_{ij} = \begin{cases} 1, & \text{Access to "j" from "i"} \\ 0, & \text{No access to "j" from "i"} \end{cases} \tag{10}$$

(2) Whether or not to travel to a particular city has a direct impact on the visit to the changed city's scenic spots, thus generating a playfulness constraint:

$$z_{jk} \leq \sum_{i=1}^{22} x_{ij} \leq 1, j \in [1,22], j \in Z, k \in [1,6], k \in Z \tag{11}$$

(3) In order to ensure that Ming will leave a city (except Wuhan) after arriving in that city, there is a traffic constraint corresponding to city i. The constraints are

$$\sum_{i=1}^{22} x_{ij} - \sum_{i=1}^{22} x_{ji} \leq 1, i, j \in Z \tag{12}$$

Wuhan unique flow constraint:

$$\sum_{i=1}^{22} x_{1i} - \sum_{i=1}^{22} x_{i1} = 1 \tag{13}$$

Also considering the existence of the probability of repeated entry into the same city, the range of values of u_i is restricted to be:

$$u_1 = 0, 1 \leq u_i \leq 21, i = 2,3, \dots, 22. \tag{14}$$

(4) Each edge does not constitute a sub-circle, i.e.:

$$u_i - u_j + 22x_{ij} \leq 21, i = 1,2, \dots, 22, j = 2,3, \dots, 22. \tag{15}$$

For the single-objective model, this paper through the lingo software, to obtain the most "A-star" experience in three weeks of travel through the corresponding city to play the total number of attractions, as well as 3A level scenic spots, 4A level scenic spots, 5 A level scenic spots in the number of Fig. 3.

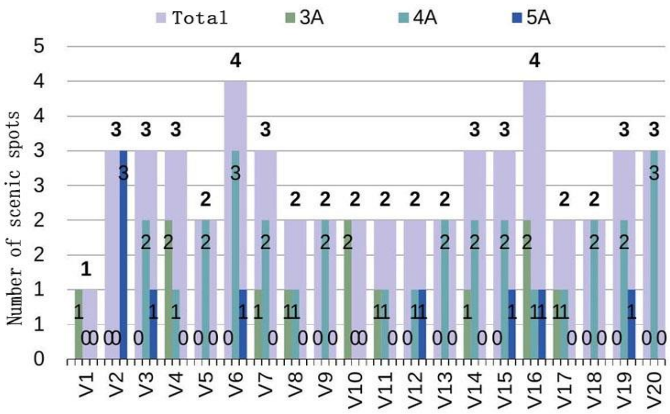

Fig. 3 Number and location of specific scenic spots

4.2. Multi-Objective Planning Model

The optimization model is improved to multi-objective planning, so that the goal of the trip is to simultaneously satisfy the goal of obtaining the most "A-star" experience and the time spent on driving and playing every day should be as little as possible, to reduce the fatigue of the journey and improve the happiness of the trip.

Let the decision variables be z_{ij}, A_{ij} where z_{jk} is whether to play k attractions in j, indicating the corresponding number of stars in k scenic spots in j, then the objective function is as follows. Maximize the "A-star" experience:

$$\max f_1(x) = \sum_{j=1}^{22} \sum_{k=1}^{6} z_{jk} * A_{jk}, j, k \in Z \tag{16}$$

Drive and play time minimization:

$$f_2(x) = \sum_{i=1}^{22} \sum_{j=1}^{22} e_{ij} * x_{ij} + \sum_{i=1}^{22} \sum_{j=1}^{22} z_{ik} * T_{ik}, i, j, k \in Z \tag{17}$$

Where, because one of the two objective functions is a very large dependent variable and the other is a very small dependent variable, $f_2(x)$ should be treated as a very large dependent variable first, so the total objective function is:

$$\max\{f_1(x) - f_2(x)\} \tag{18}$$

Summarizing the above and combining the constraints, the model can be described as:

$$\text{s.t.}\begin{cases} z_{jk} \le \sum_{i=1}^{22} x_{ij} \le 1, j \in [1,22]\ , j \in Z, k \in [1,6]\ , k \in Z, \\ \sum_{i=1}^{22} x_{ij} - \sum_{i=1}^{22} x_{ji} \le 1, i,j \in Z, \\ \sum_{i=1}^{22} x_{1i} - \sum_{i=1}^{22} x_{i1} = 1, \\ u_1 = 0, 1 \le u_i \le 21, i = 2,3,\dots,22. \\ u_i - u_j + 22x_{ij} \le 21, i = 1,2,\dots,22, j = 2,3,\dots,22. \\ z_{jk}, x_{ij} \in \{0,1\} \end{cases} . \tag{19}$$

For the multi-objective planning model, this paper uses the linear weighting method to solve the problem. According to the requirements, the demand for the most “A-star” experience is better than the demand for reducing the driving and playing time, so the weight of the “A-star” experience objective $f_1(x)$ is set to 0.6, and the weight of the driving and playing time objective $f_2(x)$ is set to 0.4. was set to 0.4.

Because the maximum number of stars obtained for attractions in the tour and the sum of driving and playing time have different scales, they are first dimensionless. Normalization (dimensionlessness) is performed by dividing the objective function by a constant that corresponds to some value of the objective function. The constant p_1 for $f_1(x)$ is set to 204 in this paper because this value is the maximum “A-star” experience that can be obtained for 16 h of driving and playing time per day for single-objective planning. For the constant p_2 of $f_2(x)$, it is set to 252h in this paper because this value is obtained when the driving and playing time is 12h (7:00-19:00) per day for three weeks.

In summary, the above multi-objective planning is reduced to the following linear programming:

$$\max = 0.6 * \frac{\sum_{i=1}^{22} \sum_{k=1}^{6} z_{ik} * A_{jk}}{p_1} - 0.4 * \frac{\sum_{i=1}^{22} \sum_{j=1}^{22} e_{ij} * x_{ij} + \sum_{i=1}^{22} \sum_{j=1}^{22} z_{ik} * T_{ik}}{p_2}, i,j,k \in Z \tag{20}$$

$$\text{s.t.}\begin{cases} z_{jk} \le \sum_{i=1}^{22} x_{ij} \le 1, j \in [1,22]\ , j \in Z, k \in [1,6]\ , k \in Z, \\ \sum_{i=1}^{22} x_{ij} - \sum_{i=1}^{22} x_{ji} \le 1, i,j \in Z, \\ \sum_{i=1}^{22} x_{1i} - \sum_{i=1}^{22} x_{i1} = 1, \\ u_1 = 0, 1 \le u_i \le 21, i = 2,3,\dots,22, \\ u_i - u_j + 22x_{ij} \le 21, i = 1,2,\dots,22, j = 2,3,\dots,22, \\ z_{jk}, x_{ij} \in \{0,1\} \end{cases} . \tag{21}$$

Using the linguo software, the optimal solution of the above linear programming is found to have an “A-star” rating of 137, the total time spent on driving and playing is 252h, and the time spent on driving and playing is 9.14h per day.

5. Route Planning Based on Visiting the Most Attractions

5.1. Modeling

In this section, the requirement is to visit the greatest number of attractions with a limited amount of funds, so the funds are divided into bus fare and entrance fee to be used, so the decision variables are x_{ij}, z_{jk}.

Where,

$$z_{jk} = \begin{cases} 1, \text{ Playing “ k” attractions in “ j” places} \\ 0, \text{ No “ k ‘ sightseeing in ’ j ” land} \end{cases}, k \in [1,6]\ , k \in Z. \tag{22}$$

Then the cost of traveling to city j is $c_{ij}{}^{*}X_{ij}$.

Where c_{ij} denotes the cost of a single trip from city i to city j.0020

$$c_{ij} = 0.8^* d_{ij}, x_{ij} = \begin{cases} 1, & \text{Access to "j" from "i"} \\ 0, & \text{No access to "j" from "i"} \end{cases} \tag{23}$$

Meanwhile, let the ticket price of attraction k in city j be F_{jk}. The cost of attraction ticket D_{jk} used up by Ming to visit attraction k in city j is:

$$D_{jk} = 3^* F_{jk} \tag{24}$$

Therefore, the objective function is:

$$F = \sum_{j=1}^{22} \sum_{k=1}^{6} z_{jk}, j, k \in Z \tag{25}$$

The following constraints can be obtained:

(1) For the overall funding constraint:

$$\sum_{i=1}^{22} \sum_{j=1}^{22} c_{ij}^* x_{ij} + \sum_{j=1}^{22} \sum_{k=1}^{6} D_{jk} {}^* Z_{jk} \leq 8000, i, j, k \in Z \tag{26}$$

(2) Whether or not to travel to a particular city will have a direct impact on the visit to the change city attraction, thus generating a playfulness constraint:

$$z_{jk} \leq \sum_{i=1}^{22} x_{ij} \leq 1, j \in [1,22], j \in Z, k \in [1,6], k \in Z \tag{27}$$

(3) In order to ensure that arriving at a city will leave that city (except Wuhan), there is a flow constraint corresponding to city i. The flow constraints are as follows

$$\sum_{i=1}^{22} x_{ij} - \sum_{i=1}^{22} x_{ji} \leq 1, i, j \in Z \tag{28}$$

Wuhan unique flow constraint:

$$\sum_{i=1}^{22} x_{1i} - \sum_{i=1}^{22} x_{i1} = 1 \tag{29}$$

Also considering the existence of the probability of repeated entry into the same city, a set of variables $u_j (j = 1,2, \dots ,22)$ is added, and then the constraints are added.

(3) Restrict the value range of u_j to:

$$u_1 = 0, 1 \leq u_i \leq 21, i = 2,3, \dots ,22. \tag{30}$$

(4) The edges do not constitute a sub-loop, i.e:

$$u_i - u_j + 22 x_{ij} \leq 21, i = 1,2, \dots ,22, j = 2,3, \dots ,22. \tag{31}$$

5.2. Solving the Model

The route that can visit the greatest number of attractions with a budget of $8,000 is found by using LINGO as Fig. 4.

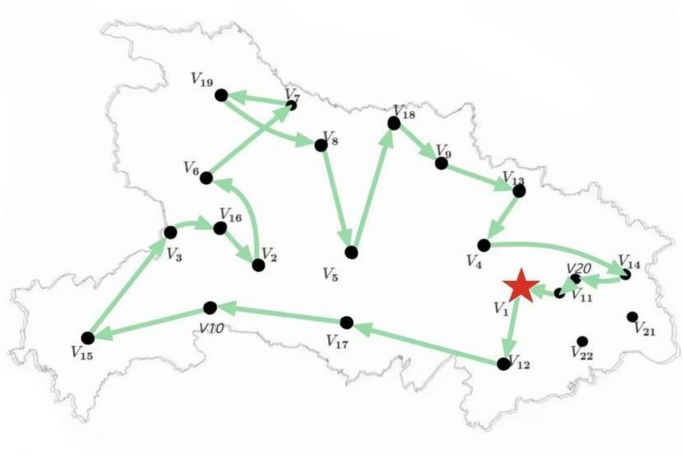

Fig. 4 Route Planning

6. Conclusion

In this paper, based on 0-1 integer programming, computer related algorithms are used to optimize the travel routes. For the different needs of self-driving tour, the corresponding model is constructed. Based on the minimum cost tour and return, the optimal self-driving route and time cost are determined with the help of 0-1 integer planning model. For the route planning to get the most "A-star" experiences in 21 days, the single-objective planning model is first solved, and then optimized to a multi-objective planning model, which balances the playing experience and the rest time. And in the case of visiting the greatest number of attractions under a limited budget, the single-objective planning model is utilized to clarify the effects of fluctuating budgets and car costs on the number of attractions visited. The 0-1 integer planning and multi-objective planning model proposed in this study effectively solves the difficult problem of tourism route planning, provides a scientific basis for actual tourism decision-making, and has important guiding significance and practical value for the planning of the tourism industry and tourists' travel arrangements[6].

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