Design of Tourist Routes in Scenic Spots : Taking Pan'an Lake Scenic Area as an Example

ABSTRACT

In this paper, we explore the application of 0-1 integer programming and mixed integer programming to solve the route design problem using the Pan'an Lake Scenic Area in Xuzhou as a case study. We aim to design scenic tour routes with the shortest walking distance and the longest visit time. We formulate the problem using a 0-1 integer programming model, with an objective function that minimizes the total route length. Constraints are established to ensure the route starts at Scenic Stone, ends at Wetland Commercial Street, each attraction is visited once, and there are no repeated paths. The research results of the article have certain reference significance for route optimization problems.

Keywords: programming model; mixed Integer Programming; optimal solution; route design.

1 Introduction

With the continuous progress of society and the improvement of people's living standards, tourism, as an important socio-economic activity, is gradually showing a growing trend in demand, becoming one of the hot topics of social research. The development of the tourism industry not only provides travelers with broadened horizons and comfortable leisure experiences but also significantly promotes the economy of various regions.

In recent years, there has been a gradual increase in attention to the design of tourist routes, reflecting the increasing demand for more in-depth and personalized tourism activities. The design of tourist routes in scenic spots, as an important part of the tourism industry chain, not only concerns the travel experience of tourists but also involves complex issues such as local economy, cultural heritage, and sustainable development. In-depth research on the design of tourist routes in scenic spots helps to enhance the competitiveness and attractiveness of the tourism industry. If the optimal tourist routes for scenic spots can be designed according to various requirements, it will not only facilitate tourists' sightseeing but also facilitate the management of scenic spot staff and improve the utilization rate of scenic spot resources. For the design of tourist routes in scenic spots, there are different design directions based on different principles for different types of scenic spots.

In the current context, some researchers have conducted in-depth studies on the design of tourist

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routes in scenic spots, which is of great significance for promoting the sustainable development of tourism and improving the overall service quality. In [1], Mu proposed six principles for the design of regional geological tourist routes, including the principle of unity of scientific value and ornamental value, highlighting characteristics, combining scientific investigation with physical exercise, typicality, historical sequence, and combining natural and cultural landscapes. Based on these principles, four geological tourist routes were designed . Based on the Floyd algorithm, Tang and Zou proposed an intelligent tourist route selection system, which calculates the shortest path between any two scenic spots and recommends the best tourist route for travelers [2], and the author in [3] designed a coastal tourism route optimization system. Wang and Liu designed the optimal tourist route to visite 11 attractions in Sichuan Province with the least tourism cost based on the Traveling Salesman Problem (TSP) and the Hamilton model [4]. Ma proposed a tourist route plan for Hanzhong City based on GPS positioning and APCGIS software, and realized the spatial visualization of tourist nodes and routes [5]. Gong and Wu designed characteristic tourist routes for the Daling Mountain Forest Park using the Hopefield algorithm [6]. The authors in [7] proposed an interactive intelligent tourism planning system that comprehensively considers multiple factors and can complete large-scale scenic spot planning using ant colony optimization algorithm. Yang designed a tourism route optimization model for the dynamic multi-objective problem of tourism routes [8]. Lu and Zhou used the actual geographic data as the research object of the tourism route problem and describes the model of the discrete particle swarm algorithm based on geographic coordinates to solve the tourism route problem [9]. In [10], the authors proposed the design of alternative multi-parameter tourist routes in the Chimborazo Wildlife Reserve based on spatial network analysis implemented in ArcGIS software. In [11, 12], the authors designed the optimal tourist routes using genetic algorithm and ant colony algorithm for the Pan'an Lake Scenic Area in Xuzhou respectively. Liu et al used the 0-1 model and exhaustive method to design the optimal tourist route for the Pan'an Lake Scenic Area in Xuzhou [13]. In [14], the authors used the greedy algorithm to optimize the tourist routes in Huangshan Scenic Area. In [15], Xiao et al designed the shortest distance tourist route for Pan'an Lake Scenic Area in Xuzhou based on the TSP model. Wang designed characteristic tourist routes for Yunnan based on the Latent Dirichlet Allocation model and multi-objective planning [16]. In recent years, the design of tourist routes in scenic spots has received increasing attention.

In recent years, integer programming (IP) has applied as an effective tool for addressing complex optimization problems across various fields, including operations research, engineering, and finance [17]. The IP involves decision variables that are restricted to integer values, making it suitable for modeling discrete decision-making problems. As an important subclass of IP is 0-1 integer programming, in which the decision variables only take on values of 0 or 1. This class of problems is particularly useful for modeling yes/no or binary decision problems, such as resource allocation, portfolio selection, and route design. Another widely used variant is mixed integer programming (MIP), where some decision variables are restricted to integer values while others can take on continuous values [18]. Mixed integer programming allows for more flexibility in modeling real-world problems by combining discrete and continuous decision variables. This versatility makes MIP suitable for a wide range of applications, including production planning, logistics optimization, and facility location.

In this paper, we will explore the application of 0-1 integer programming and mixed integer programming in solving the route design problem. Taking the Pan'an Lake Scenic Area in Xuzhou as an example, we use the 0-1 integer programming model and the mixed integer programming model to design scenic tour routes with the shortest walking distance and the longest visit time, respectively. The problem addressed here was also presented as a mathematical modeling challenge during the May 1 Cup in 2018, with data curated from the corresponding competition.

2 Basic information of the scenic area

The Pan'an Lake Scenic Area in Xuzhou is a national-level scenic area transformed from a coal mining subsidence area. The scenic area integrates wetland ecosystems, popular science education, sightseeing, leisure, and experiential activities, forming a unique tourist destination that combines natural landscapes with cultural elements. First, here are some basic facts about the Pan'an Lake Scenic Area in Xuzhou. There are several scenic spots in Pan'an Lake: ⓪ Scenic Stones, ① Tourist Service Center, ② Sunshine Lawn, ③ Forest Small Theater, ④ Children's Science Popularization Experience Area, ⑤ Children's Water Theater,⑥ Wetland Museum, and ⑦ Wetland Commercial Street. The shortest walking distances between these scenic spots are listed and the opening hours of these scenic spots are listed in Tables 1 and 2, respectively.

No. of scenic spots	⓪	①	②	③	④	⑤	⑥	⑦
⓪	0	300	360	210	590	475	500	690
①	300	0	380	270	230	285	200	390
②	360	380	0	510	230	765	580	770
③	210	270	510	0	470	265	450	640
④	590	230	230	470	0	515	260	450
⑤	475	285	765	265	515	0	460	650
⑥	500	200	580	450	260	460	0	190
⑦	690	390	770	640	450	650	190	0

Table 1: The shortest walking distance between various scenic spots (unit/m).

No. of scenic spots	**Travel time**	**Opening hours**
①	10-30	9:00-16:00
②	20-60	9:00-17:00
③	30	9:00-17:00(Open at half and on the hour)
④	30-60	9:00-17:00
⑤	20-60	9: 00-17: 00
⑥	30-60	9: 00-17: 00

Table 2: Opening hours of these scenic spots.

3 Design of the shortest walking distance route in scenic areas

One of the most common requirements when visiting a scenic area is to have the shortest walking distance. For the Pan'an Lake Scenic Area in Xuzhou, it is required to start from the Scenic Stones, walk to visit several other attractions, and finally reach the Wetland Commercial Street. All the scenic spots must pass through at least once, we want to seek the shortest walking time travel route (assuming tourist walking speed $V = 2$ km/h).

Firstly, we construct an adjacency matrix of order 8 × 8 according to Table 1, i.e.,

$$D = \begin{pmatrix} 0 & 300 & 360 & 210 & 590 & 475 & 500 & 690 \\ 300 & 0 & 380 & 270 & 230 & 285 & 200 & 390 \\ 360 & 380 & 0 & 510 & 230 & 765 & 580 & 770 \\ 210 & 270 & 510 & 0 & 470 & 265 & 450 & 640 \\ 590 & 230 & 230 & 470 & 0 & 515 & 260 & 450 \\ 475 & 285 & 765 & 265 & 515 & 0 & 460 & 650 \\ 500 & 200 & 580 & 450 & 260 & 460 & 0 & 190 \\ 690 & 390 & 770 & 640 & 450 & 650 & 190 & 0 \end{pmatrix}. \tag{3.1}$$

3.1 Optimization of total route length

Denoted by Z the total length of the tourist route, the the shortest route can be obtained by minimizing the sum of the shortest tourist distances, thus we have

$$\min Z = \sum_{i=0}^{7} \sum_{j=0}^{7} d_{ij} \times x_{ij}, \tag{3.2}$$

where $d_{ij}(i = 0, 1, \cdots, 7; j = 0, 1, \cdots, 7)$ is the distance from attraction ⓘ to attraction ⓙ and corresponds to the $(i + 1, j + 1)$th element in the adjacency matrix D, x_{ij} is a 0-1 variable, and when $x_{ij} = 1$ it represents the transition from attraction ⓘ to attraction ⓙ; if $x_{ij} = 0$, it means that there is no transition from attraction ⓘ to attraction ⓙ.

3.2 Constraints for designing the shortest walking distance in a tourist route

To design the shortest walking distance, it is necessary to establish constraints that the starting point is Scenic Stone, the ending point is Wetland Commercial Street, and each attraction has and can be reached once, while excluding circuits, thus we have the following constraints.

1. The tourist is required to start from Scenic Stone, that is, he can only start from the scenic spot ⓪ to other scenic spots, and other scenic spots cannot return to the scenic spot ⓪. So the constraint condition is:

$$\sum_{j=1}^{7} x_{1j} = 1, \ \sum_{i=1}^{7} x_{i1} = 0. \tag{3.3}$$

2. The tourist is required to end at scenic spot ⑦, which means that only other attractions can go to the attraction ⑦, and not from the attraction ⑦ to other attractions. So the constraint condition is:

$$\sum_{i=0}^{6} x_{i7} = 1, \ \sum_{j=0}^{6} x_{7j} = 0. \tag{3.4}$$

3. Assuming that each attraction is only visited once, meaning that each attraction can only enter and exit once, so the constraint conditions are:

$$\sum_{i=0, i \neq j}^{7} x_{ij} = 1, j = 1, 2, \cdots, 6; \quad \sum_{j=0, j \neq i}^{7} x_{ij} = 1, i = 1, 2, \cdots, 6. \tag{3.5}$$

4. Assuming that tourists do not take repeated paths during their travels, this means that one path only passes through once, so we have:

$$x_{ij} \times x_{ji} = 0. \tag{3.6}$$

Since the number of scenic spots is relatively few, there won't be many circuits that can be formed. Therefore, we use the inertia constraint to reduce the computational complexity required for model operation and accelerate the model's running speed [19].

Inert constraint refers to not adding this set of sub loop constraints during model establishment, and verifying the feasible solution (here, the feasible solution refers to the feasible solution without adding sub loop constraints, which may not necessarily be a feasible solution for TSP itself) after each solution is solved. If there are sub loops in the solution, the corresponding constraints of the sub loops are added to the model and the model is continued/resolved. In this way, in the vast majority of cases, we do not need to involve all sub loop constraints, but only need to add a relatively small number of constraints to solve.

3.3 Model for the shortest walking distance

For the objective function (3.2) and the constraints (3.3) - (3.6), a 0-1 integer programming model can be established to solve for the shortest walking path:

$$\min Z = \sum_{i=0}^{7} \sum_{j=0}^{7} d_{ij} \times x_{ij} \tag{3.7}$$

$$\text{s.t.} \begin{cases} \sum\limits_{j=1}^{7} x_{1j} = 1, \sum\limits_{i=1}^{7} x_{i1} = 0; \\ \sum\limits_{i=0}^{6} x_{i7} = 1, \sum\limits_{j=0}^{6} x_{7j} = 0; \\ \sum\limits_{i=0, i \neq j}^{7} x_{ij} = 1, j = 1, 2, \cdots, 6; \\ \sum\limits_{j=0, j \neq i}^{7} x_{ij} = 1, i = 1, 2, \cdots, 6; \\ x_{ij} \times x_{ji} = 0. \end{cases} \tag{3.8}$$

3.4 Results of the shortest walking distance model

Now, we employ Python to solve the 0-1 integer programming model (3.7). Several objects and functions, such as LpProblem, LpVariable, lpSum, LpMinimize, LpInteger, are imported from the PuLP library in Python to solve linear programming problems.

We can obtain the shortest walking distance route: Scenic Stones → Forest Small Theater → Children's Water Theater → Tourist Service Center → Sunshine Lawn → Children's Science Popularization Experience Area → Wetland Museum → Wetland Commercial Street. The length of the this route is 1820 meters.

4 Route design for the longest travel time in the scenic area

It is also very common to request the longest travel time when visiting a scenic area. Next, we want to design the tourist route with the longest visiting time on the premise of the shortest travel route. For the Pan'an Lake Scenic Area in Xuzhou, a tourist is required to arrive at Wetland Commercial Street before 17:00, and leave Wetland Commercial Street at 17:30. Besides, the tourist is required to visit the Wetland Commercial Street for at least 30 minutes.

Assuming that the walking speed of tourists is $V = 2$ km/h and there is no waiting time at each scenic spot, under the above conditions, design a tour route so that tourists can complete all the attractions with the longest total tour time.

4.1 Optimization of the longest travel time

Let T be the total travel time of the tourist route, the longest travel time means to maximize the sum of the travel time spent in each scenic area, so we get the objective function as follows:

$$\max T = \sum_{i=0}^{7} t_i, \tag{4.1}$$

where t_i is the visiting time of the scenic spot ⓘ. The visiting time t_i is equal to the departure time α_i of the scenic spot ⓘ minus the arrival time β_i of the scenic spot ⓘ, i.e., $t_i = \alpha_i - \beta_i$.

4.1.1 Constraints for designing the longest travel time in a tourist route

The longest visiting time should incorporate time-related constraints on top of the shortest walking distance, therefore the constraint conditions in Subsection 3.2 also hold for this model. In addition, time constraints mentioned in Table 2 need to be considered. For instance, when arriving at the scenic spot ④, it must be at either half past the hour or on the hour. So we have

1. If $x_{ij} = 1$, the time α_i to leave the scenic spot ⓘ, the walking time between the scenic spots ⓘ and ⓙ, and the time β_j to reach attraction ⓙ satisfy the following constraints:

$$M(x_{ij} - 1) \leq \beta_j - \alpha_i - \frac{d_{ij}}{V} \leq M(1 - x_{ij}),\ i = 0, \cdots, 6, j = 1, \cdots, 7, \tag{4.2}$$

   where M is a sufficiently large number that ensures that the constraint condition is valid when $x_{ij} = 1$;

2. Table 2 lists the constraints on the travel time and constraint time for each scenic spot. For the convenience of calculation, the hourly system has been converted to a minute system. Thus, we have

$$\begin{cases} \beta_0 - \alpha_0 = 12 \times 60; \\ \beta_1 \geq 9 \times 60, \alpha_1 \leq 16 \times 60; \\ \beta_i \geq 9 \times 60, \alpha_i \leq 17 \times 60, i = 2, 4, 5, 6; \\ \beta_3 + w = 30 \times p, p \in \mathbb{Z}^+; \\ \beta_7 \leq 17 \times 60, \alpha_7 = 17.5 \times 60; \\ 10 \leq t_1 \leq 30, 20 \leq t_2 \leq 60, t_3 = 30, 30 \leq t_4 \leq 60; \\ 20 \leq t_5 \leq 60, 30 \leq t_6 \leq 60, t_7 \geq 30, \end{cases} \tag{4.3}$$

   here the w is the waiting time because the scenic spot ③ only opens at half and on the hour.

4.2 Route design model for the longest travel time

Based on the above analysis, a mixed integer programming model can be established to solve the route design for the longest travel time.

$$\max T = \sum_{i=0}^{7} t_i \tag{4.4}$$

$$\text{s.t.} \begin{cases} \sum\limits_{j=1}^{7} x_{1j} = 1, \sum\limits_{i=1}^{7} x_{i1} = 0; \\ \sum\limits_{i=0}^{6} x_{i7} = 1, \sum\limits_{j=0}^{6} x_{7j} = 0; \\ \sum\limits_{i=0, i\neq j}^{7} x_{ij} = 1, j = 1, 2, \cdots, 6; \\ \sum\limits_{j=0, j\neq i}^{7} x_{ij} = 1, i = 1, 2, \cdots, 6; \\ x_{ij} \times x_{ji} = 0; \\ M(x_{ij} - 1) \leq \beta_j - \alpha_i - \frac{d_{ij}}{V} \leq M(1 - x_{ij}),\ i = 0, \ldots, 6, j = 1, \cdots, 7, i \neq j; \\ \beta_0 - \alpha_0 = 12 \times 60; \\ \beta_1 \geq 9 \times 60, \alpha_1 \leq 16 \times 60; \\ \beta_i \geq 9 \times 60, \alpha_i \leq 17 \times 60, i = 2, 4, 5, 6; \\ \beta_3 + w = 30 \times p, p \in \mathbb{Z}^+; \\ \beta_7 \leq 17 \times 60, \alpha_7 = 17.5 \times 60; \\ 10 \leq t_1 \leq 30, 20 \leq t_2 \leq 60, t_3 = 30, 30 \leq t_4 \leq 60; \\ 20 \leq t_5 \leq 60, 30 \leq t_6 \leq 60, t_7 \geq 30. \end{cases} \tag{4.5}$$

4.3 Analysis of solution results

For the mixed integer linear programming problem with multiple constraints mentioned above, as long as the feasible domain is non empty and bounded, the linear programming must have a solution and exist on the vertices or boundaries of the feasible domain.

By using Python to solve the optimization problem (4.4), we obtain three sets of optimal solutions. The travel time for all three optimal solutions is 260 minutes. Here we present an optimal travel route: Scenic Stones → Sunshine Lawn → Children's Science Popularization Experience Area → Forest Small Theater → Children's Water Theater → Tourist Service Center → Wetland Museum → Wetland Commercial Street.

5 Conclusions

In this paper, we utilize the Pan'an Lake Scenic Area as a case study to formulate tourist routes, with the objective functions of minimizing walking distance and maximizing total travel time. The 0-1 integer programming model and mixed integer programming model are used to design tourist routes. The proposed models can effectively plan tourism routes. Similarly, this model can also be applied to similar problems such as mail delivery, aircraft route arrangement, express delivery services, vehicle route design, and so on.

However, we ignore the influence of factors such as weather, tourist preferences, and scenic area traffic on tourism route selection in its assumptions, which may lead to deviations between the results and the actual situation. In the future, appropriate improvements can be made in the model establishment to achieve better practical results.

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AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between all authors. Author JD wrote the first draft of the manuscript. Author WH and Author ZH performed the simulation. Author LH wrote reviewed, and edited the manuscript. All authors read and approved the final manuscript.

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