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Original Paper

Multi-Objective Programming-Based Tour Route Planning

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Abstract

This paper develops personalized 144-hour itineraries for foreign tourists in China, accounting for differences in preferences, attraction density, travel time, and the combined cost of admission and transportation. For Problem 1, multi-source appendix data were merged into a single Excel sheet and attractions with missing ratings were removed. Ratings were then sorted, showing 5 as the maximum score; 2,563 attractions achieved this level, and cities were grouped by their counts of 5-point (BS) attractions. Among 334 cities with BS attractions, 16 cities have at least 15 such sites, with the top ten including Sansha, Wujiaqu, Yuxi, Yiyang, Tianmen, Yantai, Weifang, Greater Khingan Range, Alar, and Xingtai.

For Question 2, an evaluation system covering city scale, environmental protection, cultural heritage, and transport convenience was built. After standardization, indicator weights were derived via the entropy method and combined with TOPSIS to rank cities; SPSS produced the "Top 50 Most Desirable Cities for Foreign Tourists."

For Questions 3–5, attraction clustering along the southeast coast was used to reduce travel time, and multi-objective integer programming models were solved in Matlab. The resulting itineraries cover 14 cities (124.8 hours, 1,812 yuan), 13 cities under stronger cost constraints (107.38 hours, 868 yuan), and a mountain-themed 10-city route (111.95 hours, 1,443 yuan).

Keywords

Entropy Weight Method-Topsis, Multi-Objective Planning Model, Integer Linear Programming

1. Problem Restatement

1.1 Background

Currently, an increasing number of foreign tourists are visiting China. Planning itineraries for them not only enhances their travel experience but also attracts more international visitors, thereby boosting China's tourism industry. When designing these itineraries, it is essential to comprehensively consider factors such as attraction ratings, duration of visits, admission fees, and transportation costs. This ensures foreign tourists can explore more cities within the 144-hour visa period.

1.2 Problem Information

Foreign tourists may stay in China for up to 144 hours after entry and depart from any airport near their city of arrival.

Principle for selecting top attractions in each city: Choose only one attraction with the highest rating per city.

The appendix provides data on 35,200 tourist attractions across 352 cities in China. Each Attraction includes information such as name, website, address, recommended visit duration, and ticket details.

1.3 Problem to Solve

Problem 1: Aggregate, organize, filter, and statistically analyze the appendix data to identify the highest-rated attractions; calculate the number of attractions nationwide receiving the highest rating; list the city with the most highest-rated attractions and the top ten cities by this metric.

Problem 2: Conduct a comprehensive evaluation of 352 cities based on optimal sightseeing principles, incorporating factors such as city size, environmental sustainability, and cultural heritage. Select the top 50 cities.

Problem 3: Plan a specific itinerary for a foreign tourist entering from Guangzhou. The itinerary must meet the tourist's requirements, visit as many cities as possible within 144 hours, and prioritize an overall positive travel experience.

Question 4: Re-plan a specific itinerary for foreign tourists to maximize the number of cities visited while minimizing total expenses for admission tickets and transportation.

Problem 5: Create a personalized, detailed 144-hour itinerary for a foreign tourist, maximizing visits to mountains while minimizing total admission and transportation costs.

2. Problem Analysis

2.1 Analysis of Problem One

Problem 1 primarily requires organizing and analyzing data to understand the rating distribution across 35,200 attractions.Analysis of the provided attachment reveals a large dataset with missing values. To identify the highest-rated attraction and the city with the most attractions receiving top ratings, this paper first organizes the data using Excel, then filters and consolidates it to determine the highest attraction rating and the number of top-rated attractions per city.

2.2 Analysis of Question 2

For Question 2, we first collected evaluation indicators related to factors such as city size, environmental protection, and cultural heritage. We preprocessed the data to exclude invalid city records.Subsequently, an Entropy Weighting Method-Topsis model was constructed using four evaluation indicators—city size, cultural heritage, transportation convenience, and environmental protection—to conduct a comprehensive assessment of 352 cities. The top 50 cities by final score were designated as the "50 Most Desirable Cities for Foreign Tourists."

2.3 Analysis of Question Three

For Question 3, data preprocessing is required first to organize the duration of visits, admission fees, and transportation costs for each attraction. Route planning must maximize the number of cities visited within 144 hours while ensuring a positive experience. This requires understanding the geographical distribution of the 50 attractions, followed by constructing a multi-objective planning model that prioritizes provinces with dense attraction clusters to meet tourist demands.

2.4 Analysis of Problem 4

For Problem 4, the tour objective builds upon Problem 3 by requiring the lowest possible admission fees and total costs. Therefore, admission fees and transportation costs must be incorporated into the considerations from Problem 3. Simultaneously, the route planning scope expands nationwide. A new multi-objective planning model is constructed, defining new objective functions and solving them by combining the weights of each objective function.

2.5 Analysis of Problem 5

For Problem 5, data processing is first required to identify the highest-rated mountain landscapes in each city and compile corresponding admission and transportation costs. Subsequently, a multi-objective planning model is constructed to design the tour itinerary.

To maximize the number of mountains visited within 144 hours, the route is planned based on regions with dense mountain scenery distribution in China, minimizing travel time and costs.

3. Model Assumptions

1. Foreign tourists are assumed to have a 144-hour stay period in China and may depart from any airport near their city of entry.

2. Assume high-speed rail travel is available between attractions in different cities, with fares set at the lowest available rate between any two cities.

3. It is assumed that no extreme weather events occur during the 144-hour period after foreign tourists enter China.

4. It is assumed that all attractions are fully operational, and the recommended visit duration for each attraction represents the actual time required for sightseeing.

5. Assume tourists spend 50 hours on basic daily needs like eating and sleeping during their 144-hour stay, with an average of 1 hour for travel to and waiting at high-speed rail stations.

4. Symbol Explanation

Table 1. Symbol Explanation

Symbol	Description
X_{ij}	The jth indicator for the ith city
E_j	Indicator Entropy Value
W_j	Indicator Weight
X_i	City i Attractions
C_i	Ticket price for the i-th city's attraction
h_i	Transportation cost for the i-th city's attraction
X_1	Population size
X_2	Annual normalized vegetation index for the city
X_3	Number of scenic facilities
X_4	Number of high-speed rail stations and lines
a_i	City score for the i-th city
b_i	Scenic Spot Rating Results for City i
e_i	Recommended duration for visiting the i-th city attraction
d_i	Transportation time for the i-th city attraction

5. Problem 1: Model Construction and Solution

5.1 Model Construction

The attached data for this problem provides information on 100 attractions across various cities. The file contains numerous entries, and some attraction data is missing. This paper first uses Excel to consolidate the 352 city datasets into a single Excel table, removing attractions with missing data. Next, attraction ratings are filtered to identify the highest-rated attractions. Counting the number of attractions receiving the highest rating reveals the total number of highest-rated attractions nationwide. Finally, categorizing and counting the highest-rated attractions provides the number of highest-rated attractions per city.

5.2 Model Solution and Analysis

After consolidating the data for this problem in Excel and removing invalid entries, sorting the attraction ratings in descending order reveals the highest rating is 5 points.Statistics on attractions receiving the highest score reveal that 2,563 attractions nationwide achieved this top rating, distributed across 334 cities. The specific number of top-rated attractions per city is detailed in the appendix.

Among these 334 cities, 16 possess at least 15 attractions with the highest score. This paper identifies these 16 cities as having the highest concentration of top-rated attractions.

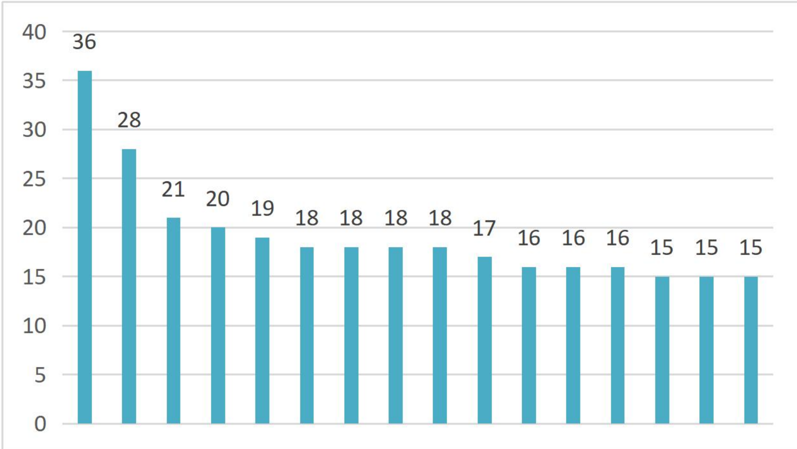

Figure 1. Cities with the Most Top-Rated Attractions

As shown in Figure 1, 16 cities received the most BS attractions: Sanya ( ), Wujiaqu, Yuxi, Yiyang, Tianmen, Yantai, Weifang, Greater Khingan Range, Aral, Xingtai ( ), Zigong, Zhoukou, Baoting, Ya'an, Neijiang, Baoding. Among these, the top ten cities by number of BS attractions are: Sanya ( ), Wujiaqu, Yuxi, Yiyang ( ), Tianmen,Yantai, Weifang, Greater Khingan Range, Aral, Xingtai.

6. Establishment and Solution of the Second Model

This study requires a quantitative analysis based on the characteristics of 352 cities in China, including urban scale, environmental protection, cultural heritage, and transportation convenience. A model will be established to conduct a comprehensive evaluation of these 352 cities, from which the "50 Cities Most Desired by Foreign Tourists" will be selected.Therefore, in this question, specific indicators are extracted from the available data to measure each city's characteristics. Based on these indicators, an Entropy Weighting Method-TOPSIS evaluation model is established for solution, providing a comprehensive evaluation of the 352 cities and drawing final conclusions.

6.1 Data Preprocessing

During the organization of data for the four evaluation indicators, missing data were identified for some cities, which could hinder model establishment and subsequent city evaluations. Consequently, cities with missing data were excluded, leaving 314 valid city datasets. Subsequently, data normalization was performed to eliminate the influence of units of measurement.

6.2 Model Establishment

6.2.1 Determining the Evaluation Indicator System

Problem 1 requires a quantitative analysis of the 352 cities listed in Appendix 1 based on urban scale, environmental protection, cultural heritage, transportation convenience, climate, and cuisine to identify the “50 Most Desirable Cities for Foreign Tourists .”This study employs population size to represent urban scale, annual normalized vegetation index (NVI) to represent environmental protection, number of scenic attractions and facilities to represent cultural heritage, and number of high-speed rail stations and lines to represent transportation accessibility. The evaluation indicator system is established as follows:

Table 2. Comprehensive City Evaluation Index System

Objective Layer	Criterion Layer	Indicator Layer		
		Indicator	Variable	Direction
Comprehensive Urban Evaluation Indicator System	City Size	Population Size	X_1	+
	Environmental Protection	Annual Normalized Difference Vegetation Index (NDVI)	X_2	+
	Cultural Heritage	Number of Scenic Spot Facilities	X_3	+
	Transportation Convenience	Number of High-Speed Rail Stations and Routes	X_4	+

Partial indicator data is illustrated in the figure below:

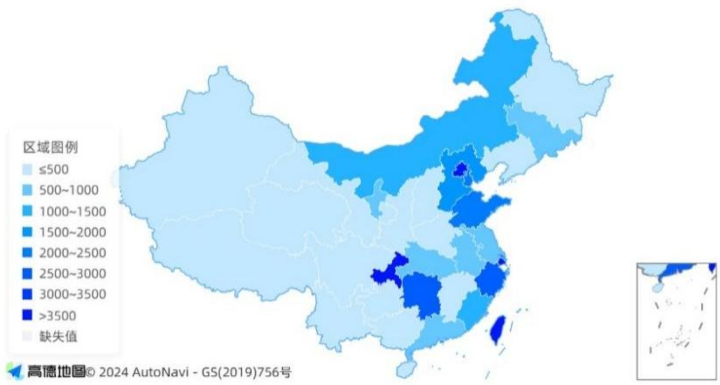

Figure 2. Distribution Map of Scenic Spot Facilities by City

Note. Created using the GS(2019)756 standard map downloaded from AutoNavi Maps, with no modifications to the base map boundaries.

Figure 3. Yearly Distribution Map of Normalized Difference Vegetation Index (NDVI) by City

Note. Created using the GS(2019)756 standard map downloaded from AutoNavi Maps, with no modifications to the base map boundaries.

6.2.2 Data Sources and Data Standardization Processing

The data analyzed in this study primarily originate from China's county-level census data, MODIS datasets, and the China Statistical Yearbook. For individual missing data points, these were treated as invalid and excluded. Let there be n cities and m indicators. The jth indicator for the ith city is denoted as X_{ij} (i=1,2,3,…,n; j=1,2,3,…,m). Based on , the following evaluation decision matrix is established :

$$X_{ij}=\begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

Next, standardize the data. Since the established evaluation indicator system contains both positive and negative indicators, different processing methods are required. The processing approach is as follows :

$$r_{ij}=\frac{x_{ij}-x_{min}}{x_{max}-x_{min}} \tag{2}$$

$$r_{ij}=\frac{x_{max}-x_{ij}}{x_{max}-x_{min}} \tag{3}$$

6.2.3 Calculation of Indicator Weights Based on Entropy Weighting Method

(1) First, determine the entropy values for each indicator

$$E_j=-\frac{1}{ln(n)}\sum_{i=1}^{n}\left(Z_{ij}lnZ_{ij}\right) \tag{4}$$

whereZ_{ij} represents the weight value of the i-th sample in the j-th indicator.

(2) Calculate the divergence degree for each indicator

$$D_j=1-E_j \tag{5}$$

(3) Determine the weights

$$W_j = \frac{D_j}{\sum_{j=1}^{m} D_j} (j=1,2,\ldots,m) \quad (6)$$

The weights for indicators in the comprehensive evaluation system of 352 cities were calculated, with results shown in Table 2.

6.2.4 Calculation of Indicator Weights Based on the TOPSIS Method

This study employs the Entropy Weight-TOPSIS integrated evaluation method. After standardizing the required data, the decision matrix R is obtained, followed by the determination of positive and negative ideal solutions, as shown in Table 3. The distances from each city to the positive and negative ideal solutions (D_i^+ and D_i^-) and the comprehensive scores for each city (C_i) are then calculated.Subsequently, the 352 cities were ranked based on their comprehensive scores, yielding the optimal ranking (Feng & Huang, 2024), as shown in Table 4.

6.3 Model Solution and Analysis

This study employed SPSS to solve the model, with results presented in the following Table.

Table 3. Summary of Weight Calculation Results Using Entropy Weight Method

Primary Indicators	Secondary Indicators	Information Entropy Value *E*	Information Utility Value *D*	Weighting *Coefficient W*
City Size	Population Size	0.9474	0.0526	19.71%
Cultural Heritage	Number of Scenic and Historic Sites	0.9237	0.0763	28.57%
Transportation Convenience	Number of high-speed rail stations and lines	0.8688	0.1312	49.15%
Environmental Protection	Annual normalized vegetation index	0.9931	0.0069	2.57%

Table 4. Positive and Negative Ideal Solution Results

Indicator	Positive Ideal Solution A+	Negative Ideal Solution A-
City Size	0.199	0.002
Cultural Heritage	0.289	0.003
Transportation Convenience	0.496	0.005
Environmental Protection	0.026	0.000

Among these, the positive ideal solution A+ represents the maximum value of the evaluation indicators, while the negative ideal solution A- represents the minimum value of the evaluation indicators.

Table 5. TOPSIS Evaluation Calculation Results

City	Positive Ideal Solution DistanceD_i^+	Negative Ideal Solution DistanceD_i^-	Relative ProximityC_i	Ranking Result
Beijing	0.063	0.585	0.903	1
Chongqing	0.165	0.462	0.737	2
Guangzhou	0.16	0.448	0.736	3
Shanghai	0.163	0.442	0.731	4
Shenzhen	0.219	0.407	0.65	5
Chengdu	0.241	0.362	0.6	6
Hangzhou	0.348	0.282	0.448	7
Xi’an	0.381	0.244	0.39	8
Wuhan	0.398	0.205	0.34	9
Qingdao	0.401	0.203	0.337	10
Wenzhou	0.474	0.238	0.335	11
Tianjin	0.403	0.202	0.334	12
Zhengzhou	0.406	0.198	0.328	13
Nanjing	0.408	0.198	0.326	14
Shenyang	0.411	0.199	0.326	15
Quanzhou	0.501	0.241	0.324	16
Fuzhou	0.45	0.204	0.312	17
Foshan	0.445	0.195	0.305	18
Jinan	0.428	0.174	0.289	19
Suzhou	0.448	0.182	0.289	20
Dalian	0.438	0.171	0.281	21
Xiamen	0.438	0.167	0.276	22
Ningbo	0.464	0.173	0.272	23
Changsha	0.443	0.164	0.271	24
Lanzhou	0.455	0.165	0.266	25
Harbin	0.455	0.153	0.252	26
Kunming	0.453	0.151	0.25	27
Guiyang	0.481	0.125	0.207	28
Hefei	0.485	0.121	0.2	29
Urumqi	0.493	0.122	0.198	30
Shijiazhuang	0.506	0.116	0.187	31

Taizhou	0.533	0.119	0.182	32
Wuxi	0.506	0.112	0.182	33
Dongguan	0.542	0.12	0.181	34
Zunyi	0.495	0.109	0.18	35
Jinhua	0.536	0.107	0.167	36
Ganzhou	0.538	0.107	0.166	37
Xilingol League	0.558	0.103	0.156	38
Jieyang	0.551	0.097	0.149	39
Xuzhou	0.521	0.091	0.149	40
Baoding	0.545	0.095	0.149	41
Shaoxing	0.531	0.093	0.149	42
Zhangzhou	0.548	0.095	0.148	43
Nanyang	0.538	0.091	0.145	44
Linyi	0.546	0.092	0.145	45
Huai’an	0.519	0.087	0.143	46
Nanning	0.524	0.088	0.143	47
Luoyang	0.53	0.087	0.14	48
Shantou	0.537	0.087	0.14	49
Nanchang	0.522	0.084	0.138	50

Where D_i^+ and D_i^- represent the distance between the evaluation target and the positive/negative ideal solution, respectively; C_i indicates the proximity to the optimal solution. A higher value signifies greater closeness to the optimal solution, meaning a higher likelihood of being among the 50 cities most desired by foreign tourists. Therefore, cities are ranked based on their C_i values, and the top 50 cities in this ranking constitute the “50 Cities Most Desired by Foreign Tourists.”

As shown in the table above, the “50 Most Desirable Cities for Foreign Tourists” are: Beijing, Chongqing, Guangzhou, Shanghai, Shenzhen, Chengdu, Hangzhou, Xi’an, Wuhan, Qingdao, Wenzhou, Tianjin, Zhengzhou, Nanjing, Shenyang, Quanzhou, Fuzhou, Foshan, Jinan, Suzhou, Dalian, Xiamen, Ningbo, Changsha, Lanzhou, Harbin, Kunming, Guiyang,Hefei, Ürümqi, Shijiazhuang, Taizhou, Wuxi, Dongguan, Zunyi, Jinhua, Ganzhou, Xilingol League, Jieyang, Xuzhou, Baoding, Shaoxing, Zhangzhou, Nanyang, Linyi, Huai’an, Nanning, Luoyang, Shantou, and Nanchang. The geographical distribution of these cities is illustrated in the figure below:

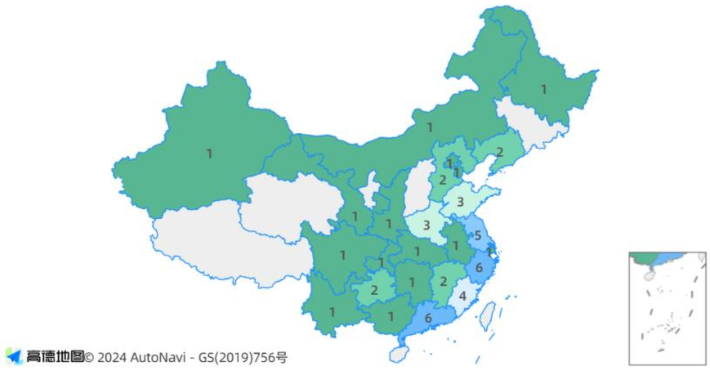

Figure 4. Geographic Distribution Map of 50 Cities

Note. Created using the GS(2019)756 standard map downloaded from AutoNavi Maps, with no modifications to the base map boundaries.

7. Establishment and Solution of the Three-Problem Model

To provide specific itineraries tailored to tourists' requirements, it is necessary to comprehensively consider maximizing the overall travel experience while visiting as many cities as possible within the 144-hour entry period. Therefore, a multi-objective planning model is proposed, ultimately transformed into a single-objective linear programming model for solution.

7.1 Data Preprocessing

First, adhering to the principle of selecting the best attraction per city—choosing only the highest-rated attraction in each city—the data for the 50 "most desirable cities for foreign tourists" was sorted in descending order using "attraction rating" as the primary keyword and "recommended attraction duration" as the secondary keyword. The highest-rated attraction with the shortest recommended duration was selected from each city, resulting in 50 attractions.Given the large dataset, to simplify the solution process, we visualized the spatial distribution of the 50 attractions ( ) and their locations ( ). The results are shown in Figure 1. The figure reveals that attractions are predominantly clustered around Guangdong Province, and since the tour enters China via Guangdong, we aim to minimize travel time while visiting as many cities as possible. Therefore, we preliminarily determined that the route should primarily cover the area surrounding Guangdong Province, enabling a secondary screening of attractions.

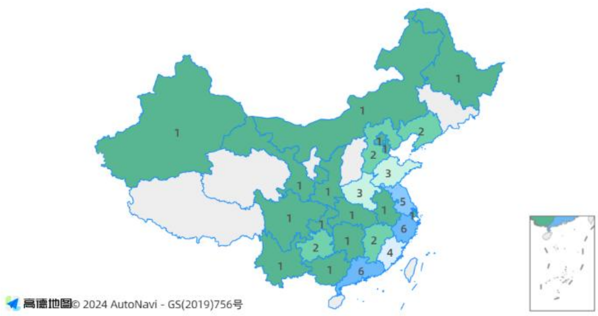

Figure 5. Location Distribution Map of 50 Scenic Spots

Note. Created using the GS(2019)756 standard map downloaded from AutoNavi Maps, with no modifications to the base map boundaries.

Second, the city scores ( ) are based on the comprehensive city evaluation indicators from Question 2. The attraction scores and recommended visit durations ( ) utilize data provided in the appendix. Missing data points were obtained from databases such as CNKI and the China Statistical Yearbook.

For travel time calculations, since travelers exclusively use high-speed rail between cities, official intercity high-speed rail durations were referenced. Considering practical travel circumstances, an additional hour was added to account for security checks, waiting times, and other delays, resulting in the final travel time estimates.

Based on the above, data was filtered and summarized using Excel software. The final results are presented in the attachment.

7.2 Model Development

First, introduce 0-1 variables:

$$X_i=\begin{cases}1, & Visiting\ the\ scenic\ spots\ in\ the\ city\ number\ i\\ 0, & Not\ \text{visiting the scenic spots in the i-th city}\end{cases} \tag{7}$$

The multi-objective optimization model features two objective functions: maximizing the number of cities visited and optimizing the overall travel experience. The specific multi-objective optimization model is as follows:

The objective function for multi-objective optimization is:

$$maxf_i=\sum_{i=1}^{25} X_i \tag{8}$$

$$maxf_i=\frac{1}{2}\sum_{i=1}^{25} a_i+\frac{1}{2}\sum_{i=1}^{25} b_i \tag{9}$$

Wherea_i represents the city score for the i-th city obtained from Problem 2, andb_i denotes the scenic spot score for the i-th city.

The objective function for the final single-objective optimization is obtained as:[4]

$$f_{(x)}=\frac{1}{2}\sum_{i=1}^{25}X_i+\frac{1}{2}\left(\frac{1}{2}\sum_{i=1}^{25}a_i+\frac{1}{2}\sum_{i=1}^{25}b_i\right) \tag{10}$$

The constraints are:

$$s.t.\begin{cases}\sum_{i=1}^{25}X_i\,e_i+\sum d_i\leq 94\\ 0\leq X_i\leq 1\end{cases} \tag{11}$$

where e_i represents the recommended sightseeing duration for the i-th city's scenic spot, and d_i denotes the travel time for the i-th city's scenic spot.

7.3 Model Solution and Analysis

Using MATLAB, the single-objective integer linear programming model and objective function derived from the model were solved to address the single-objective minimization problem. Based on this, the negative value was taken as the final result, as shown in the table below:

Table 6. Multi-Objective Optimization Model Solution Results

City	X_i	City	X_i	City	X_i	City	X_i
Guangzhou-Foshan	1	Zhangzhou-Xiamen	1	Jinhua-Hangzhou	1	Wuxi-Nanjing	0
Foshan-Dongguan	1	Xiamen-Quanzhou	1	Hangzhou-Shaoxing	0	Nanjing-Huai'an	0
Dongguan-Shenzhen	1	Quanzhou-Fuzhou	1	Shaoxing-Ningbo	1	Huai'an-Xuzhou	0
Shenzhen-Jieyang	1	Fuzhou-Wenzhou	1	Ningbo-Shanghai	1	Xuzhou-Linyi	0
Jieyang-Shantou	1	Wenzhou-Taizhou	1	Shanghai-Suzhou	0	Linyi-Jinan	0
Shantou-Zhangzhou	0	Taizhou-Jinhua	1	Suzhou-Wuxi	0	Jinan-Qingdao	0

As shown in the table above, tourists depart from Guangdong Province and travel through Fujian Province, Zhejiang Province, and Shanghai for sightseeing. Their specific itinerary begins in Guangzhou, proceeding through Foshan, Dongguan, Shenzhen, Jieyang, Shantou, Xiamen, Quanzhou, Fuzhou, Wenzhou, Taizhou, Jinhua, Hangzhou, Ningbo, and finally Shanghai. As illustrated below:

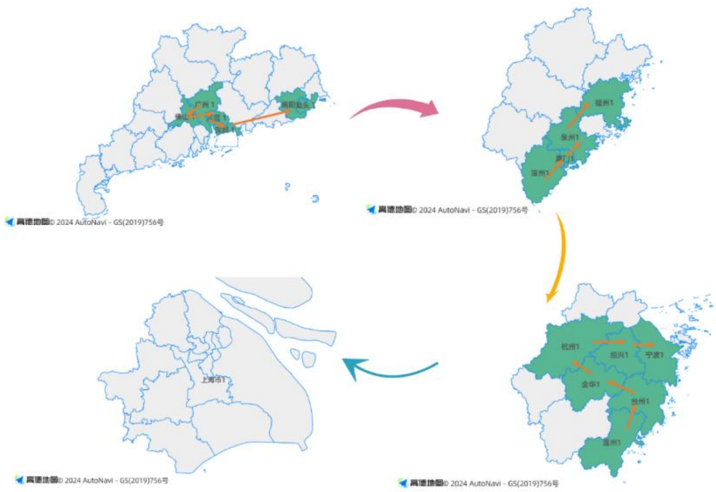

Figure 6. Schematic Diagram of Tourist Travel Routes

Note. Created using the GS(2019)756 standard map downloaded from AutoNavi Maps, with no modifications to the base map boundaries.

The total travel time was calculated as 124.8 hours, with admission fees amounting to 670 yuan and transportation costs totaling 1,142 yuan. The combined expenses for admission and transportation reached 1,812 yuan, and the number of attractions visited was 14.

8. Establishing and Solving the Fourth Problem Model

When re-planning the route based on the new sightseeing objectives, it remains necessary to comprehensively consider visiting as many cities as possible within the 144-hour entry period while minimizing admission and transportation costs. Therefore, we again consider establishing a multi-objective planning model, determining new objective functions, and combining the weights of each objective function to establish a single-objective planning model for solution.

8.1 Data Preprocessing

First, to enhance solution accuracy by utilizing as much data as possible, the "50 Cities Most Desired by Foreign Tourists" data obtained from Problem 2 was sorted in descending order using "attraction rating" as the primary keyword, followed by "attraction ticket price" and "visiting duration" as secondary keywords. This process yielded the 50 cities required for model solution.

Second, the processing methods for attraction duration, ticket prices, and travel time mirror those applied in Problem 2. For transportation costs, actual high-speed rail fares between cities were referenced.

Based on the above, data filtering and aggregation were performed using Excel software. The final results are presented in the attachment.

Figure 7. Transportation Costs and Ticket Prices Illustration

Note. Created using the GS(2019)756 standard map downloaded from AutoNavi Maps, with no modifications to the base map boundaries.

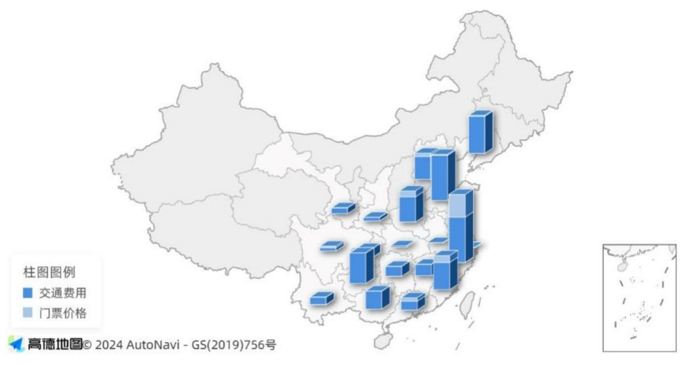

Figure 8. Transportation Time and Sightseeing Duration Diagram

Note. Created using the GS(2019)756 standard map downloaded from AutoNavi Maps, with no modifications to the base map boundaries.

8.2 Model Development

8.2.1 Objective Function Construction

(1) Visit as many cities as possible

$$maxf_i=\sum_{i=1}^{50} X_i \tag{12}$$

(2) Minimize total expenses for admission tickets and transportation

$$minf_i=\frac{1}{2}\sum_{i=1}^{50} X_i\, C_i+\frac{1}{2}\sum \mathrm{h}_i \tag{13}$$

WhereC_i represents the admission fee for the i-th city attraction, andh_i denotes the transportation cost for the i-th city attraction.

(3) Derive the single-objective linear programming function based on the objective function and its weights from the multi-objective programming model

$$f_{(x)}=\frac{1}{2}\sum_{i=1}^{50} X_i - \frac{1}{2}\left(\frac{1}{2}\sum_{i=1}^{50} X_i C_i + \frac{1}{2}\sum \mathrm{h}_i\right) \tag{14}$$

8.2.2 Construction of Constraints

Since this question only partially adjusts the sightseeing objective from the third question—shifting emphasis from maximizing overall travel experience to minimizing combined ticket and transportation costs—the constraints here remain identical to those in the multi-objective planning model for maximizing overall travel experience. Therefore, further elaboration on these constraints is omitted.

8.3 Model Solution and Analysis

Using MATLAB software, the model was reasonably solved and analyzed to obtain the data results required for route planning, as shown in the table below:

Table 7. Multi-Objective Optimization Model Solution Results

City	X_i	City	X_i	City	X_i	City	X_i
Chongqing	0	Zunyi	0	Changsha	1	Dongguan	1
Hangzhou	0	Qingdao	0	Wuhan	1	Jieyang	1
Wenzhou	0	Jinan	0	Zhengzhou	0	Shantou	1
Ningbo	0	Linyi	0	Nanyang	0	Lanzhou	0
Taizhou	0	Shenyang	0	Luoyang	0	Quanzhou	0
Jinhua	0	Dalian	0	Shijiazhuang	0	Fuzhou	0
Shaoxing	0	Ganzhou	0	Baoding	0	Xiamen	0
Kunming	0	Nanjing	1	Guiyang	0	Zhangzhou	0
Tianjin	0	Suzhou	1	Nanning	1	Beijing	0
Chengdu	0	Wuxi	1	Guangzhou	1	Hefei	1
Shanghai	0	Xuzhou	0	Shenzhen	1		
Xi'an	0	Huai'an	0	Foshan	1		

As shown in the table above, travelers can choose to depart from Guangdong Province, pass through Guangxi Province, and finally reach Hunan and Hubei Provinces. Specifically, the route starts from Guangdong Province, proceeding sequentially through Foshan, Dongguan, Shenzhen, Jieyang, Shantou, Nanning, Changsha, Wuhan, Hefei, Suzhou, Wuxi, and Nanjing. As illustrated below:

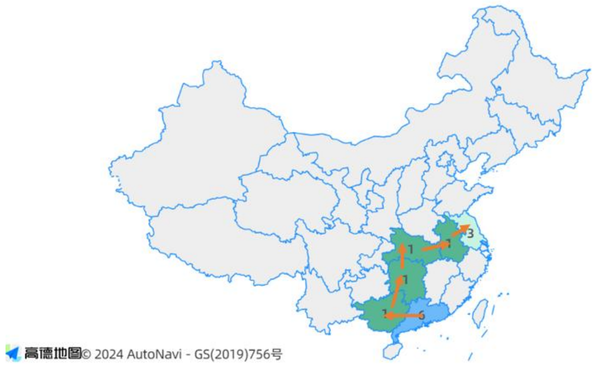

Figure 9. Tourist Route Diagram

Note. Created using the GS(2019)756 standard map downloaded from AutoNavi Maps, with no modifications to the base map boundaries.

The total cost for admission tickets and transportation was 868 yuan, with a total travel time of 107.38 hours, covering 13 cities.

9. Establishing and Solving the Problem Five Model

To identify locations of China's mountain landscapes and select optimal entry airports/cities, the objective remains to visit as many mountains as possible within 144 hours while minimizing admission and transportation costs. Therefore, establishing a multi-objective optimization model for solution remains the preliminary approach.

9.1 Data Preprocessing

First, using Excel software, we filtered attractions classified as "mountains" and removed invalid data for non-mountain landscapes. Given the requirement to visit only the highest-rated mountain per city and the expanded scope to 352 cities in the appendix, we sorted all data sequentially by attraction rating, admission price, and visit duration. This process selected the highest-rated mountain in each city, yielding the final set of attractions for study.

Second, since this study requires selecting entry airports and cities, we visualized the distribution of China's mountain landscapes based on the preprocessed data. Using a "data-visualization integration" approach for analysis, the results are shown in the figure below:

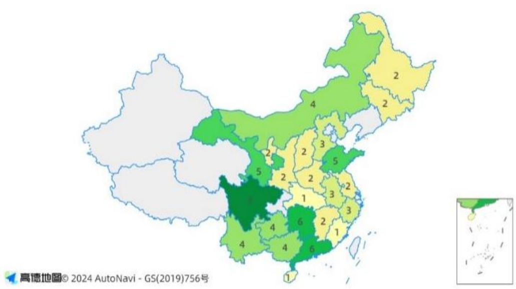

Figure 10. Distribution Map of Mountain Scenery in China

Note. Created using the GS(2019)756 standard map downloaded from AutoNavi Maps, with no modifications to the base map boundaries.

The map indicates that mountain landscapes are predominantly distributed in Sichuan Province and its surrounding areas. Therefore, selecting Enyang Airport in Bazhong City, Sichuan Province, as the entry airport and city is reasonable. This choice maximizes the opportunity to visit numerous mountain landscapes while meeting the requirement of minimizing transportation costs.Therefore, to further streamline data and simplify the solution process, adhering to the principle of minimizing transportation costs, we selected provinces with abundant mountain scenery in and around Sichuan Province as the primary research subjects. Remote cities without high-speed rail infrastructure were excluded as invalid data, thereby implementing a secondary screening of research subjects.

Ticket prices primarily rely on data from the appendix. For attractions not listed in the appendix, prices disclosed on the official websites of the attractions were used as the basis.

The treatment of transportation costs and travel time follows the approach outlined in Question 3: add one hour to the actual high-speed rail travel time between cities to account for security checks, waiting periods, and other contingencies. The actual high-speed rail fare between cities is used as the transportation cost for this calculation.

Finally, the required data is summarized, with the results shown in the table below:

Table 8. Data Preprocessing Results

City	Name	Ticket Price	Time Required	Transportation Cost	Travel Time
Bazhong City	Royal Mountain Scenic Area	0	2.5	0	0
Guang'an City	Metasequoia Villa	0	4	0.7	20
Luzhou City	Sanhua Mountain Scenic Area	75	4	1.5	280
Nanchong City	Baiyunshan	0	2.5	1	70
Yibin City	Junlian Gulou Mountain	70	4	0.5	40
Zigong City	Rong County, Baita Mountain	0	1.5	3	157
Changde	Taohua Mountain Scenic	50	0.75	1	63

City	Area Pole Slide				
Loudi City	Dacheng Mountain	0	2.5	1.5	130
Shaoyang City	Nanshan Scenic Area	100	12	0.3	24
Yueyang City	Yushan	0	1	3	170
Zhangjiajie City	Tianmen Mountain Gate	250	6	0.7	44
Bijie City	Chashan	45	2.5	4	300
Liupanshui City	Meihua Mountain Fantasy Passion Valley	115	2	2.5	155
Tongren City	Wujiang Small Mountain Town	115	6	1	90
Chaozhou City	Shibishan	0	1.5	2	340
Huizhou City	Lianhuashan	65	6	2	190
Jiangmen City	Qingshanchui	0	2.5	1.5	130
Shaoguan City	Shaoshan Mountain	7	1	3	270
Shenzhen	Hangjia Green Eco-Home Resort	150	12	0.5	230
Zhaoqing City	Xinghu Villa	150	12	1	280

9.2 Model Development

Since the sightseeing objectives in this section are identical to those in Problem 4, the only modification is expanding the study scope from the 50 cities most desired by foreign tourists to the 352 mountain views listed in the appendix. All other conditions and requirements remain consistent. Therefore, we only need to update the meaning of the 0-1 variable `$X_i$ ` in the objective function and constraints. It now represents the i-th mountain view among the 352 mountain views, rather than the i-th city attraction among the 50 cities.

9.3 Model Solution and Analysis

Using MATLAB to solve the multi-objective optimization model for the filtered mountain scenery data yielded accurate and reasonable results, as shown in the table below:

Table 9. Multi-Objective Optimization Model Solution Results

City	X_i	City	X_i	City	X_i	City	X_i
Bazhong City	1	Zigong City	0	Zhangjiajie City	0	Huizhou City	0
Guang'an City	1	Changde City	1	Bijie City	0	Jiangmen City	0
Luzhou City	1	Loudi City	1	Liupanshui City	1	Shaoguan City	0
Nanchong City	1	Shaoyang City	0	Tongren City	1	Shenzhen City	0
Yibin City	1	Yueyang City	1	Chaozhou City	0	Zhaoqing City	0

As shown in the table above, entering China via Bazhong City in Sichuan Province and traveling to Guizhou, Hunan, and Guangdong provinces maximizes the opportunity to explore diverse mountain landscapes while minimizing admission fees and transportation costs. Specifically, the route involves entering China at Bazhong, then sequentially visiting Nanchong City, Guang'an City, Yibin City, Luzhou City, Liupanshui City, Tongren City, Changde City, Loudi City, and finally Yueyang City.The detailed itinerary is illustrated below:

The total cost for admission tickets and transportation is 1,443 yuan, with a total travel time of 111.95 hours, covering 10 cities.

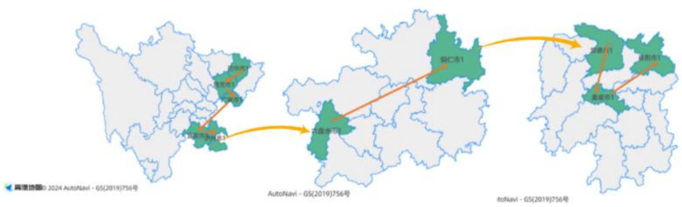

Figure 11. Detailed Tourist Route Diagram

Note. Created using the GS(2019)756 standard map downloaded from AutoNavi Maps, with no modifications to the base map boundaries.

10. Evaluation, Improvement, and Promotion of the Model

10.1 Advantages of the Model

1.The problem analysis comprehensively identifies the objectives and influencing factors; the model establishment systematically evaluates urban attractions by integrating multiple factors; variable settings are rigorous and reasonable; constraints are thoroughly considered, with reasonable assumptions made for unprovided data through data collection.

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2. Effectively consolidated and processed information from provided attachments, ensuring strong operational feasibility and facilitating relevant analyses.

3. During model development, not only was data support provided, but data visualization was also implemented. Beyond basic data visualization, this study visualizes attraction distribution and tourist routes, enabling clearer and more intuitive identification of optimal itineraries.

4. When analyzing model results, it is essential not only to interpret the findings but also to engage in rational thinking and route planning by integrating practical considerations and real-world connections. This enables the design of itineraries for foreign tourists that offer a comprehensive, enjoyable experience while saving time; it also facilitates the creation of routes minimizing ticket and transportation costs without compromising the quality of the experience.

10.2 Limitations of the Model

1.The comprehensiveness and complexity of the model's parameter settings make further optimization challenging.

2.Constraints based on real-world assumptions and considerations make it difficult to obtain data for some relevant factors, reducing the accuracy of results.

10.3 Model Improvements

1. Only four relevant factors were selected in Problem (2). A more comprehensive approach should be adopted to consider and collect data on additional relevant factors for a holistic evaluation.

2. For problems (3), (4), and (5), relevant models can be used to conduct reasonable verification of the results, thereby improving their accuracy.

10.4 Model Extension

The comprehensive evaluation model constructed in this paper can be extended to assess other subjects. Similarly, the multi-objective planning model can be applied to other planning problems, such as supermarket procurement issues and mode choice for transportation.

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