Fire station layout assessment in tourism-type city based on fire risk: A case study of Dujiangyan City

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Abstract: With the development of tourism and the acceleration of urbanization, tourist cities have sprung up like bamboo shoots. Large population flow and more cultural relics are the characteristics of the current tourist city, which brings greater fire risk. The current research pays little attention to fire safety problems in tourist cities. This article takes the urban area of Dujiangyan, a tourist city, as the research object, and uses the superposition tool of GIS to make a fire risk grade map with a total of 9 factors of regional characteristics and architectural characteristics superimposed by weight. The result shows that there are still many areas with high fire risk in Dujiangyan, such as the ancient urban area where tourists gather and the southwest sub-area of Dujiangyan urban area. Based on the positioning and distribution model, 6 new fire station layout points are selected, and the responsibility division map of 9 fire stations in Dujiangyan City is finally obtained, which provides a reference for the layout of fire stations in Dujiangyan City.

1. Introduction

A tourist city refers to a city with unique natural scenery or cultural resources that can attract tourists and have reception capacity, with scenic spots as the core and the tourism industry as the main body [1]. With the continuous expansion of tourist areas in the city, fire safety in the city is facing new challenges, and the fire station space layout in the fire system greatly affects the level of urban fire protection, so attention should be paid to the construction of urban fire stations. Empirical research on optimizing fire services has covered multiple countries such as Australia, the United States, and China. Many studies have developed models to measure the operating costs, response time, and service delivery of fire stations by maximizing coverage of demand areas[2].Nowadays, intelligent technology is gradually entering the field of fire research Intelligent technologies such as the Internet of Things, big data, cloud, drones, and geographic information systems have been adopted to achieve effective fire prevention and management, enabling rapid and efficient collection and analysis of various risk factors [3]. In 2016, Church, Richard L. et al. used Internet search, geographic information system (GIS), and spatial optimization to estimate the spatial efficiency of the Los Angeles fire service [4]. In 2021, Jiang Yuncheng et al. used POI, DEM, and other data to study a certain area in Wuhan, and identified fire risk through the model to select fire station location [5]. In 2022, Huo Feizhou et al. simulated the distribution of fire potential in GIS and obtained the optimized location of the fire station through a multi-objective optimization algorithm[6]. This paper first investigated the fire risk in Dujiangyan City, Sichuan Province, China, and constructed a fire risk assessment system based on regional and architectural characteristics. AHP and expert scoring methods were used to assign weights to each factor, and combined with weights, the fire risk grade map was obtained in GIS. According to the requirements of the "Urban Fire Planning Code", the location-allocation model is used to optimize the location of the fire station.

2. Data sources and research methods

2.1. Data Sources

The research data include road vector data of Dujiangyan City in 2021, remote sensing satellite images of Dujiangyan City in 2021, regional characteristic factor, and building characteristic factor data (2023). The road vector data is downloaded through the National Geographic Information Resource Catalog service system, and the satellite image data is a 17-level remote sensing image downloaded by Google Maps. Regional feature factor data was obtained through the Amap open platform. Building feature data is obtained by combining satellite images and field research. Building-level analysis not only enables decision-makers to strategically allocate new fire stations in urban areas, but also helps to enhance fire safety management within communities [7]. All the above data are open data.

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2.2. Analytic Hierarchy Process

The research index system combines macro and micro factors, chooses regional and architectural characteristics as the research object, and divides 9 secondary indexes out of 2 primary indexes. Like other tourist cities, Dujiangyan has important cultural relics protection units, urban infrastructure gas stations, and the different building structures and spacing in the urban area determine the probability of fire.

2.2.1. Expert scoring method to assign weight indicators

Questionnaires were sent to 5 professionals including fire experts and university professors, and the data were input into the open-source software yaahp for calculation, and a one-time test was carried out to ensure the scientific nature. Finally, the weight values were obtained as shown in Table 1.

Table 1. Fire risk assessment factor weight index table.

Target	Primary index	Secondary index	Weight
Urban area fire risk assessment (A)	Regional feature (B1)	Existing fire station (C1)	0.1419
		Fire control key unit (C2)	0.0739
		Refueling station (C3)	0.4179
		Cultural relics and historic sites protection units (C4)	0.0329
	Architectural feature (B2)	Building structure (C5)	0.0560
		Building density (C6)	0.0939
		Building height (C7)	0.0242
		Building spacing (C8)	0.1447
		Building use (C9)	0.0146

2.2.2. Grading of evaluation factors

The regional feature data classification comes from the fire industry standard, and the building features are graded according to the site survey data and network data. The effect of various factors on the occurrence of fire is from 1 to 5. The evaluation criteria of indicators are shown in Table 2, and the results are shown in Figure 1.

Table 2. Evaluation index evaluation criteria.

Secondary index	**classify**	**fractionation**
C1	Less than 300m, 300-600m, 600-900m, 900-1200m, greater than 1200m	1, 2, 3, 4, 5
C2	Less than 200m, 200-500m, 500-800m, 800-1000m, greater than 1000m	5, 4, 3, 2, 1
C3	Less than 300m, 300-600m, 600-900m, 900-1200m, greater than 1200m	5, 4, 3, 2, 1
C4	Less than 200m, 200-500m, 500-800m, 800-1000m, greater than 1000m	5, 4, 3, 2, 1
C5	Reinforced concrete building, brick and concrete structure building, steel structure building, brick and wood structure building, wood structure building	1, 2, 3, 4, 5
C6	Use the formula: the total area of the building base/site area in the region, assign the resulting percentage, <20%, 20%-30%, 30%-40%, 40%-50%, > 50%	1, 2, 3, 4, 5
C7	<3 floors, 3-7 floors, 8-11 floors, 12-20 floors, >20 floors	1, 2, 3, 4, 5
C8	The minimum interval is 5 and the maximum interval is 1	5, 4, 3, 2, 1
C9	Other buildings, residential education and scientific research buildings, administrative office buildings, commercial and entertainment buildings, industrial buildings and storage buildings	1, 2, 3, 4, 5

2.3. Positioning the Provisioning Model

The combination of GIS and location-allocation model can solve the problem of location optimization of public service facilities, and use the minimization of facility points model and the maximization of coverage model to study site optimization. The model can be expressed as:

$$\text{Minimize facility point model: } \min\sum f_j x_j \quad (1)$$

$$\text{Constraint condition: } \sum_{j\in J} a_{ij}x_j \geq 1 \quad \forall i\in I \quad (2)$$

$$X_j \in \{0,1\} \quad \forall j \in J$$

$$\text{Maximum coverage model: } \max\sum h_i z_i \quad (3)$$

$$\text{Constraint condition: } Z_I - \sum_{j\in J} a_{ij}x_j \leq 0 \quad \forall i\in I \quad (4)$$

$$\sum_{j\in J} x_j = P \quad (5)$$

$$X_j \in \{0,1\} \quad \forall j \in J$$

$$Z_i \in \{0,1\} \quad \forall i \in J$$

Relevant conformance definition: I=set of requirement points.J=set of candidate points.aij=1 if the demand point i may be covered by the supply point at candidate point j.aij=0 if the demand point i cannot be covered by the supply point at candidate point j.Xi=1 If the supply point is located at candidate point i.Xi=0 If no supply point is located at candidate point i.fj=The fixed cost of locating the supply point at candidate point j.hi=quantity demanded at demand point i.P= number of supply points.Zi=1 if the demand point i is covered.Zi=0 if the demand point i is not covered.

3. Results and analysis

3.1. Fire risk level diagram

According to the formula: Grade =C1× weight +C2× weight +C3× weight +... +C9× weight, the natural discontinuous method in GIS was used to divide the five levels, as shown in Figure 2. The picture shows that the area of high-risk areas in the southwest part, the northeast part and the central part of Dujiangyan is larger, while the area of high-risk areas is less.

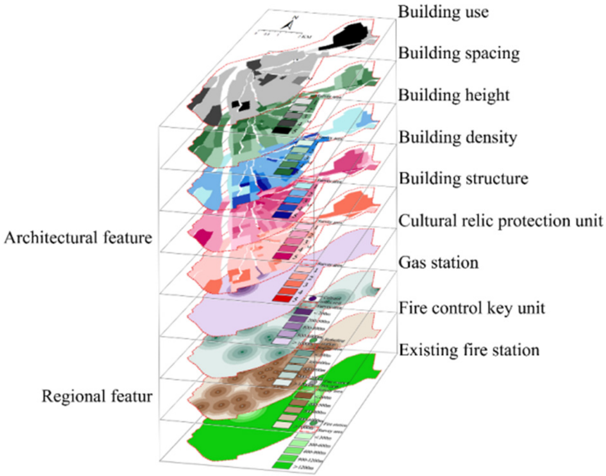

Figure 1. Each factor analysis diagram.

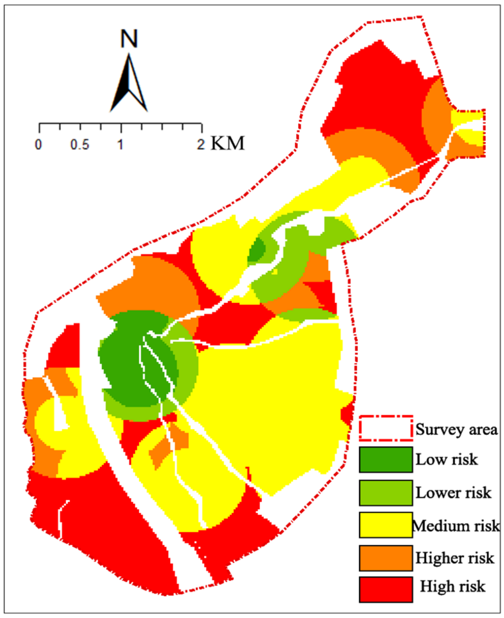

Figure 2. Dujiangyan fire risk level map.

3.2. Fire station layout optimization

In this study, 140 cells were converted into fire demand points. Establish a road traffic network model. In this study, the existing 3 fire stations were retained and 32 fire fighting candidate points were first made in GIS. The minimal facility point model is used to locate the fire station in Dujiangyan City, and the site selection scheme of 13 fire stations is obtained. Considering the actual scope of the study, maximum coverage models of 8, 9, 10, 11, and 12 sites were made, respectively, as shown in Figure 3.

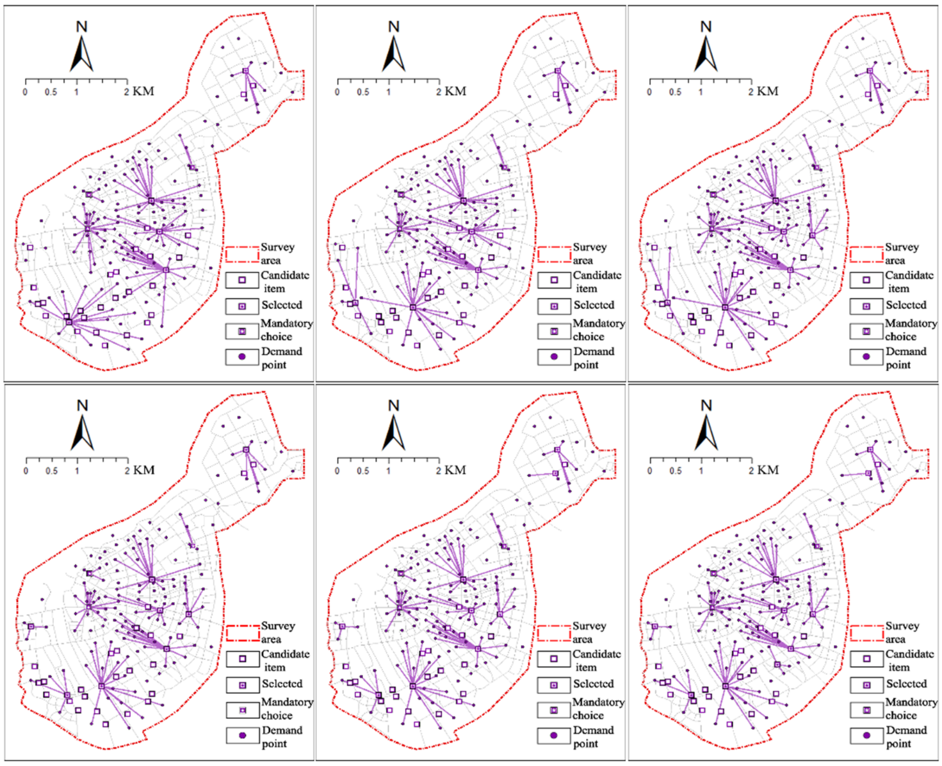

Figure 3. Maximize the coverage model.

After comparing the coverage capacity of different number of fire stations, the data is calculated using the number of fire occurrence points that can arrive at each station within 4 minutes and 18 seconds. The formula is: $k = (y - x) \div x$. Where k is the slope of the point, y is the number of fire occurrence points that the site can reach within 4 minutes and 18 seconds, and x is the number of fire occurrence points that the previous site can reach within 4 minutes and 18 seconds. The calculated results are shown in Table 3. Finally, 9 fire station schemes with the highest slope are selected. Through calculation, 71 demand points can be reached within 4 minutes and 18 seconds by the original three fire stations, with a coverage rate of 50.71%, as shown in Figure 4; Now 9 fire stations can reach 99 demand points within 4 minutes and 18 seconds, with a coverage rate of 70.71%, as shown in Figure 5, with a coverage rate increased by 20%. According to the "Urban Fire Station Construction Standards" and the urban fire station area regulation, the responsibility area distribution of 9 fire stations is reasonably adjusted, as shown in Figure 6.

Table 3. Slope values of different numbers of fire stations.

site	8	9	10	11	12	13
k	-	0.03125	0.01010	0.02000	0.00980	0.00971

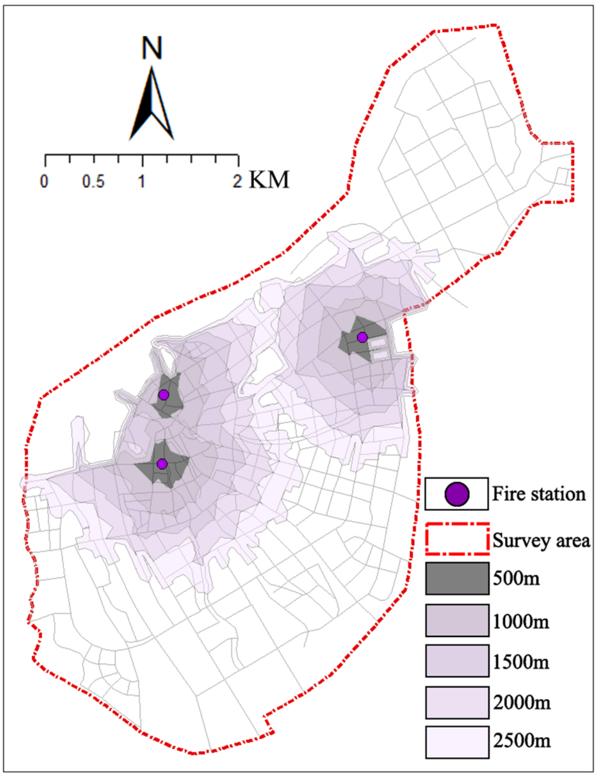

Figure 4. Fire truck travel distance map- before planning.

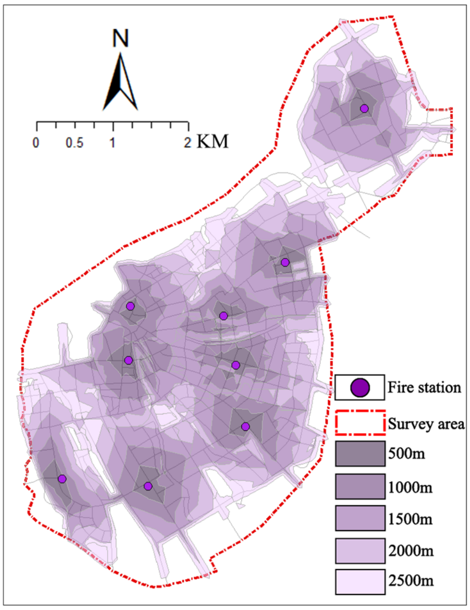

Figure 5. Fire truck travel distance map - after planning.

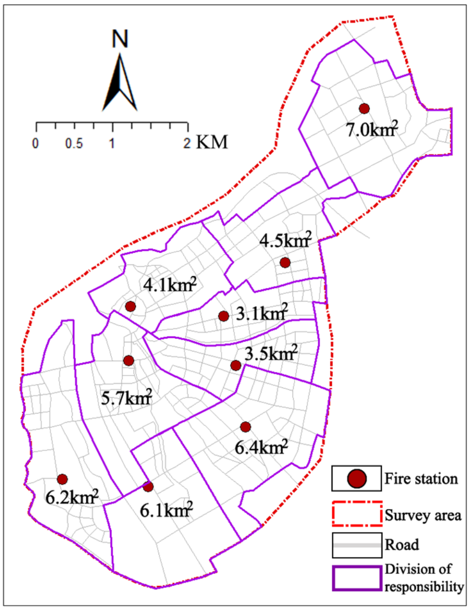

Figure 6. Responsibility zoning chart.

4. Conclusion

This paper builds a fire risk assessment system by summarizing the relevant literature of tourism city spatial structure and the specific status of Dujiangyan. In GIS, the fire risk level map of Dujiangyan city is obtained by superposition analysis of various factors based on weight, and the layout plan of fire station is obtained by comparison of positioning and distribution model. The results show that the new 6 fire stations effectively make up for the problem of large area of responsibility of the original fire stations, and the conclusion is preliminatively recognized by the fire management department. The quality of fire rescue in Dujiangyan city has been improved.

After field investigation and verification, the locations of the six fire stations to be added all belong to the land use category that allows fire protection construction. The new fire stations at Xinyu Avenue and Guanwen Road are located in the urban expansion area, which can better support the future development of the city. In addition, from the current supply of urban public fire infrastructure, the government will still occupy a dominant position in the coming time, so local governments should maintain the investment of financial subsidies and incorporate the construction of fire infrastructure into the annual financial budget.

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