

The Influence of Community Opening on Road Traffic Based on AHP and Road Saturation Method

--Take Jinyintan Avenue Airport Second Channel as an Example

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Abstract: A comprehensive analysis of the impact of community opening on road traffic was conducted, and the relevant conclusions of community opening based on the road saturation model of analytic hierarchy process and normal distribution were given. Starting from simple roads, analyze the traffic congestion situation of different traffic section structures, screen the factors affecting road traffic, and take the Airport Second Passage on Jinyintan Avenue as an example to analyze the traffic road conditions after the opening of the community, visualize the data, and give suggestions for the opening of the community.

Keywords: AHP, Normal distribution, Road saturation model, Visualizationin, Community opening.

1. Restatement of the problem

According to the "Several Opinions on Further Strengthening Urban Planning, Construction and Management Work" issued by The State Council in 2016, Article 16 stipulates the promotion of the block system. In principle, no more sealed-off residential communities will be built. Existing residential communities and large courtyards of units should be gradually opened up to achieve the publicization of internal roads. The aim is to increase the network density by promoting the construction of open communities. Divert the total traffic flow to relieve the dredging pressure on the main roads.

2. Problem raising

Start from real life. In the case of different types of residential areas with open roads, the following two problems should be solved respectively:

(1) Set out on a simple path. Analyze the traffic congestion situation of different traffic section structures and summarize the main factors affecting the road conditions in the community.

(2) Select areas with relatively heavy traffic congestion (Airport Second Passage + school district), analyze the traffic road conditions after the opening of the community, and put forward suggestions for improving the congestion situation.

3. Model Assumptions

This paper intends to establish multiple road models to solve the above two problems. Before establishing the model, first propose the hypothetical conditions for the model to hold:

- (1) Assume no interference from non-motorized vehicles
- (2) Suppose that in a short period of time, the traffic volume hardly changes
- (3) Suppose the road conditions within the community are not taken into account

4. Model Establishment

4.1. Index evaluation based on AHP

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making and evaluation method that combines qualitative and quantitative approaches. It decomposes decision-related elements into a hierarchy, including the goal layer, criteria layer, and alternatives layer, and ranks the decision options based on human judgment, followed by qualitative and quantitative analysis. This method structures and quantifies human thought processes, using mathematics to provide a quantitative basis for analysis, decision-making, evaluation, forecasting, and control. The goal layer represents the objective of the decision or the problem to be solved. The criteria layer consists of the factors or decision criteria to be considered. The alternatives layer includes the available options for decision-making. Weights are determined through a pairwise comparison matrix, which compares the relative importance of all factors in the current layer with respect to a single factor in the upper layer. By evaluating the influence of each factor on the goal, their relative weights are established, resulting in a judgment matrix. Subsequently, a consistency check is performed on the hierarchical ranking to verify whether it meets an acceptable level of consistency.

Table 1 Scale of Comparative Judgment

Qualitative comparison results	Digital quantification
Factor 1 is equally important compared to Factor 2	1
Factor 1 is slightly more important than Factor 2	3
Factor 1 is strongly more important than Factor 2	5
Factor 1 is significantly more important than Factor 2	7
Factor 1 is absolutely more important than Factor 2	9
The relative importance between Factor 1 and Factor 2 falls between the above levels	2, 4, 6, 8

4.2. Road Saturation Model Based on Normal Distribution

Based on practical experience, as the number of intersections increases, the main road is affected accordingly, which will restrain the growth of traffic flow—leading to traffic congestion. Therefore, the number of intersections cannot increase indefinitely without control. To assess the impact of residential neighborhood openness [15] on traffic congestion, this paper defines a road congestion coefficient based on the normal distribution function [1], expressed as:

$$k = e^{-\frac{R^2}{2\sigma^2}}, \quad R = \min(X, Y) \quad (1)$$

Therefore, it can be concluded that: When the traffic flow at the exit intersection or road is at its minimum (0), $R=0$ and $k=1$; When $R \neq 0$, the value of k progressively decreases and asymptotically approaches 0.

To accurately evaluate the impact of residential neighborhood openness on road traffic flow and determine a critical threshold, this study introduces a road saturation model[3]. Road saturation is one of the key indicators reflecting the level of service (LOS) of a roadway, which is influenced by factors such as segment ilength, traffic demand, travel speed, vehicle density, and travel time. In this context, the road network saturation is defined as the ratio of traffic volume to capacity per unit time in an urban road network, expressed by the following formula:

$$S = \frac{V}{C} \quad (2)$$

Here, V represents the maximum road traffic capacity, expressed as:

$$V = (X + Y) \bullet K \quad (3)$$

Here, C denotes the maximum road capacity, defined as the maximum number of vehicles that a unit length of road can accommodate. A higher saturation value indicates a lower level of service, meaning the road is more congested.

In China, road congestion levels and service levels are typically classified into the following four grades[12] based on saturation values:

Table 2 Saturation value

Level of Service (LOS)	Road Congestion Level
LOS I (Grade 1)	Smooth traffic flow with excellent service quality (Saturation range: 0-0.6)
LOS II (Grade 2)	Moderate congestion with good service quality (Saturation range: 0.6-0.8)
LOS III (Grade 3)	Heavy congestion with poor service quality (Saturation range: 0.8-1.0)
LOS IV (Grade 4)	Severe congestion with unacceptable service quality (Saturation >1.0)

The critical threshold is set at $S=0.6$, which serves as the demarcation point between congested and normal traffic conditions. The formula is expressed as:

$$S = \frac{(X + Y)e^{-\frac{R^2}{2\sigma^2}}}{C} = 0.6 \quad (4)$$

5. Model Solution

5.1. One road-Index evaluation based on the road saturation model

Taking the model of Kaixuan Jiayuan community as an example (as shown in Figure 1), according to the investigation, the relevant data of the roads around the community within a week can be obtained (as shown in Tables 3, 4 and 5).

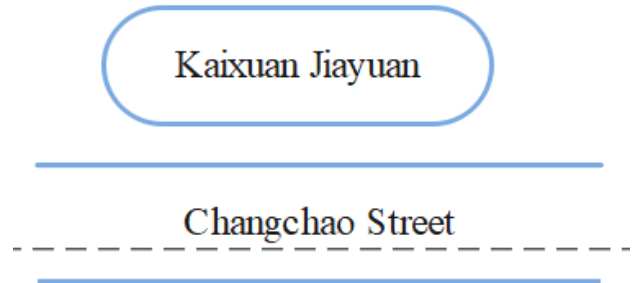


Figure 1: One road around the neighborhood

As shown in the above picture, there is only one road around the community. Before the community was opened, vehicles passing through this road only had the driving route of this road. However, after the community was opened, vehicles entering the community, but since there is only this one road around, vehicles entering the community will most likely return to this road.

Table 3 The road traffic conditions before the opened community

Traffic demand	road speed	average headway	effective service time	effective coefficient
1653.28	40	2.10	3600	0.75

Table 4 The road traffic conditions after the opening of the community

Traffic demand	road speed	average headway	effective service time	effective coefficient
1667.35	40	2.10	3600	0.78

Table 5 The saturation of roads before and after the opening of the Kaixuan Jiayuan community

Time	Before	After
Road saturation	0.49	0.47

From the above solution results, it can be known that before the opening of the community, the road saturation of the transportation network [14] was relatively low, that is, the road traffic in this section was relatively smooth and the service level was good. After the opening of the community, the degree of reduction in the road saturation of the surrounding traffic network is relatively slight, that is, the impact on road traffic after the opening of the community is nearly equal to that before the opening, and it can be considered that there is no impact.

5.2. Two or more

5.2.1. Hierarchical analysis

There are many evaluation indicators for the traffic capacity of the roads around the residential area [4], such as the traffic volume on the main roads, vehicle speed, the number of entrances and exits of the residential area,

geographical location, the time of high and low peak hours for vehicles, and the number of intersections with the main roads, etc. To reduce the workload and effectively complete the investigation, taking the Hongqi Apartment Community (referred to as District H hereinafter for convenience) (as

shown in Figure 2) and the Changhongli Community (referred to as District L hereinafter) (as shown in Figure 3) as examples, a hierarchical structure model is constructed (as shown in Figure 4).

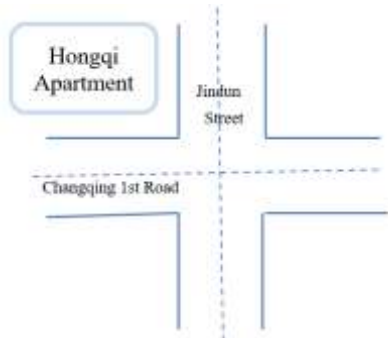


Figure 2 Hongqi Apartment Community

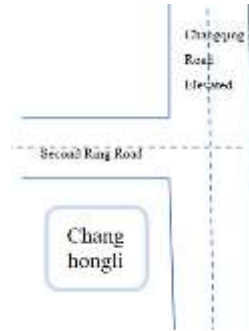


Figure 3 Changhongli Community

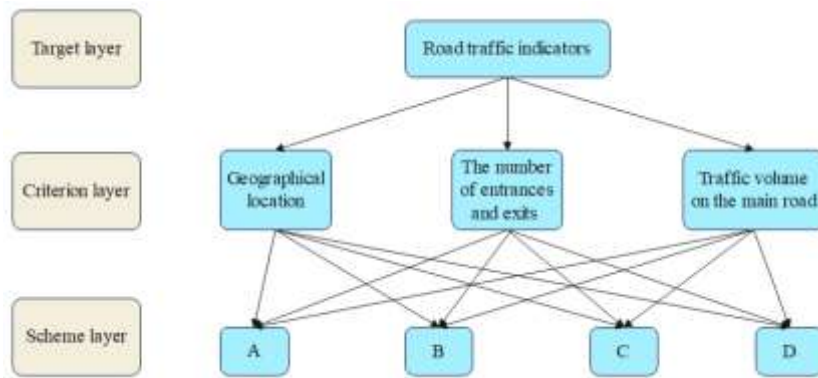


Figure 4 Hierarchical analysis structure diagram

Among them, "A" represents after the opening of Area L and Area H. "B" represents before the opening of Area L and after the opening of Area H. "C" represents before the opening of Area L and after the opening of Area H. "D" represents the period before the opening of Area L and the period before the opening of Area H.

By means of consulting materials, data, etc., the judgment matrix A from the criterion layer to the target layer is constructed as follows:

$$A = \begin{pmatrix} 1 & 2 & 3 \\ 1/2 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{pmatrix}$$

Select a quantitative criterion CI (consistency Index) to measure the degree of inconsistency of the matrix:

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.0046$$

Among them, λ is the maximum eigenvalue of matrix A, and n is the order of matrix A

According to the table 6, taking RI=0.52, we have:

$$CR = \frac{CI}{RI} = 0.010 < 0.1$$

Table 6 Random consistency index

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.52	0.89	1.12	1.24	1.32	1.41	1.45

Therefore, matrix A has satisfactory consistency. At this time, the weights of the geographical location of the community, the number of entrances and exits of the community, and the traffic flow on the main road to the traffic conditions around the community are (0.5838, 0.2412,

0.1750).

5.2.2. Consistency check

The judgment matrix from the construction scheme layer to the geographical location of the cell is

$$B = \begin{pmatrix} 1 & 1/2 & 5 & 6 \\ 1/2 & 1 & 3 & 4 \\ 1/5 & 1/3 & 1 & 2 \\ 1/6 & 1/4 & 1/2 & 1 \end{pmatrix}$$

Taking RI=0.89, we have:

$$CR = \frac{CI}{RI} = 0.0127 < 0.1$$

Therefore, matrix B satisfies the consistency test.

The score of four plans (0.5219, 0.2928, 0.1137, 0.0715).

The judgment matrix from the construction scheme layer to the number of entrances and exits of the community is

$$C = \begin{pmatrix} 1 & 1 & 3 & 4 \\ 1 & 1 & 3 & 4 \\ 1/3 & 1/3 & 1 & 2 \\ 1/4 & 1/4 & 1/2 & 1 \end{pmatrix}$$

$$CR = \frac{CI}{RI} = 0.0077 < 0.1$$

Therefore, matrix C satisfies the consistency test.

The score of four plans (0.3849, 0.3849, 0.1428, 0.0874).

The judgment matrix of the traffic flow from the construction scheme layer to the main road is

$$D = \begin{pmatrix} 1 & 1 & 2 & 3 \\ 1 & 1 & 2 & 3 \\ \frac{1}{2} & \frac{1}{2} & 1 & 2 \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{2} & 1 \end{pmatrix}$$

$$CR = \frac{CI}{RI} = 0.0039 < 0.1$$

Therefore, matrix D satisfies the consistency test.

The score of four plans (0.3509,0.3509,0.1891,0.1091).

Total scores of the four schemes

$$(0.5838 \quad 0.2412 \quad 0.1750) \begin{pmatrix} 0.5219 & 0.2928 & 0.1137 & 0.0715 \\ 0.3849 & 0.3849 & 0.1428 & 0.0874 \\ 0.3509 & 0.3509 & 0.1891 & 0.1091 \end{pmatrix} \\ = (0.4589 \quad 0.3252 \quad 0.1339 \quad 0.0819)$$

As can be seen from the above, the influence of the geographical location of the community, the number of entrances and exits of the community, and the traffic flow on the main roads on the road capacity is different. According to matrix A, the geographical location of the community has the greatest impact, followed by the number of entrances and exits of the community, and finally the traffic volume. According to the final score of the plan, compared with before the opening, the traffic score of the surrounding roads in both communities has significantly improved after the opening. The road utilization rate is high, and the probability of relative traffic congestion has decreased. After the opening of the community, it has a significant impact on the Changhongli section. The traffic utilization rate of the roads around Hongqi Apartment is lower than that of Changhongli.

5.2.3. Longitudinal Comparison of Peak Hours and Off-peak Hours

By means of reading literature and data, we choose JinDun Street, a road surrounding the Hongqi Apartment complex. Before the opening of the Hongqi Apartment, the average traffic volume of JinDun Street was 7137 vehicles per hour, with an average speed of 30.22 km/h. We selected the Second Ring Road main road around the ChangHongli Apartment as the reserach subject. Before the opening of the ChangHongli residential area, we found that the average traffic volume of the Second Ring Road main road was 9766 vichels per hour, with an average speed of 25.87 km/h(as shown in Figure 5).

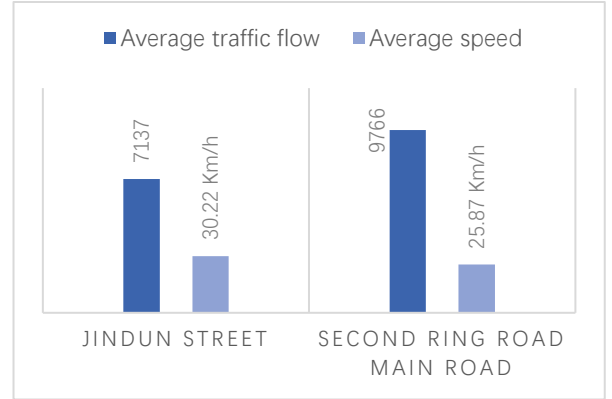


Figure 5 The average traffic volume and average speed of JinDun Street and Second Ring Road main road

According to the inverse proportional relationship between the vehicle exit rate and traffic flow[8], the exit rates were 1.33 and 1.51. Assuming the vehicle entry rate was 0.6, researchers calculated the average traffic flow and speed by using MATLAB.

Based on theoretical studies, the traffic density significantly increases during the peak hours and would lead to the traffic jam. The relationship between vehicle speed and traffic density under such conditions is defined:

$$V = V_m \ln\left(\frac{k_j}{k}\right) \quad (5)$$

However, when during the off-peak hours, the traffic density is lower with improved traffic flow efficiency. The relationship between vehicle speed and traffic density under such conditions is defined:

$$V = V_f e^{-\frac{k}{km}} \quad (6)$$

Comparative the road performance metric data before and after opening of Hongqi Apartment and ChangHongli residential area obtained(as shown infigure6-9):

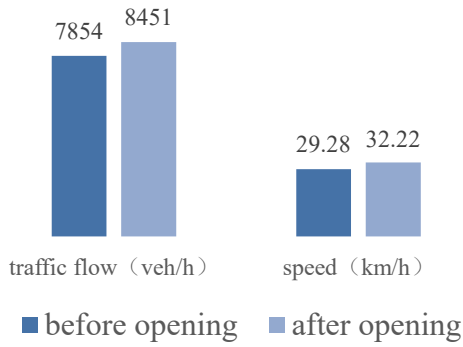


Figure 6 Hongqi Apartment (JinDun Street)
Comparison of traffic flow and speed during peak hours before and after opening

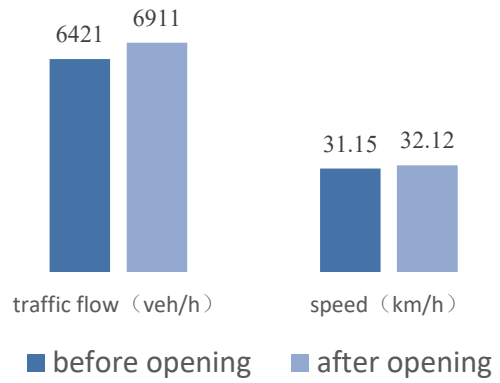


Figure 7 Hongqi Apartment (JinDun Street)
Comparison of traffic flow and speed during off-peak hours before and after opening

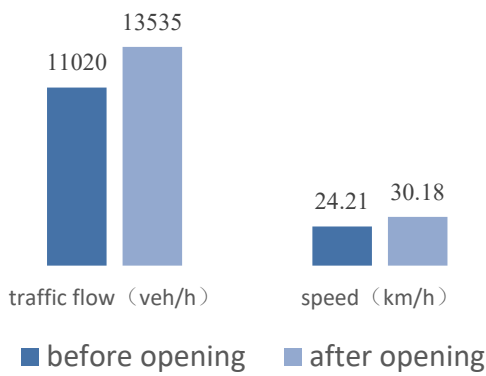


Figure 8 ChangHongli (Second Ring Road)
Comparison of traffic flow and speed during peak hours before and after opening

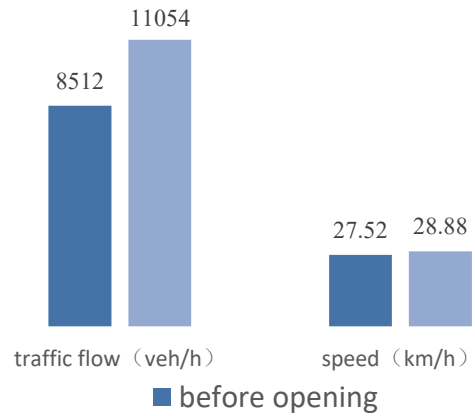


Figure 9 ChangHongli (Second Ring Road)
Comparison of traffic flow and speed during off-peak hours before and after opening

Based on the two scenarios analyzed above, it is obvious that after the opening both of Hongqi Apartment and ChangHongli residential area, the traffic capacity [13] of surrounding roads significantly improve, whether it is located along Second Ring Road (main road) or JinDun Street (neighborhood road). Evidently the traffic condition of residential area located beside main road has more notable improvement than where located around neighborhood streets. Furthermore, for the same residential area, opening during peak hours leads to a more pronounced enhancement in traffic capacity, whereas its impact during off-peak hours remained relatively marginal.

5.2.4. Question Solution

As it is shown in figure 10, the research selected Henda YuJing Residential area where is near a university in Wuhan, with the nearby Second Airport Expressway designated as the major arterial route. Assuming that the residential area have a one-way two-lane road section of 2.5 kilometers in length, excluding heavy trucks, and passenger cars with an average length of 4 meters. This study aims to find the impact of the complex's opening on surrounding road traffic conditions.

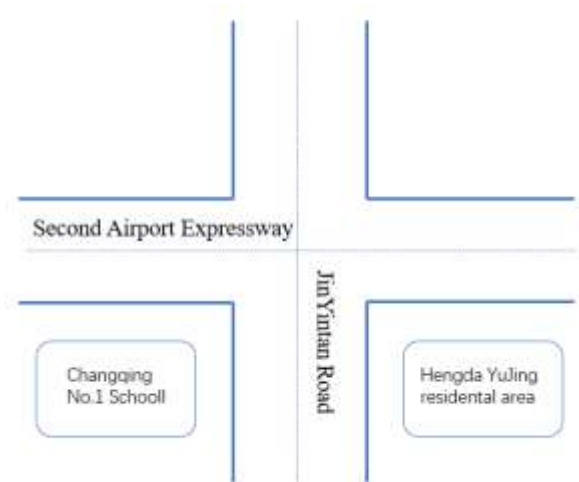


Figure 10 Henda YuJing Residential
By reading relevant data, assuming that the traffic flow at the sub-neighborhood intersection is x , the traffic flow on the main road is y , and the traffic flow measured during the time period is z (as shown in figure 11).

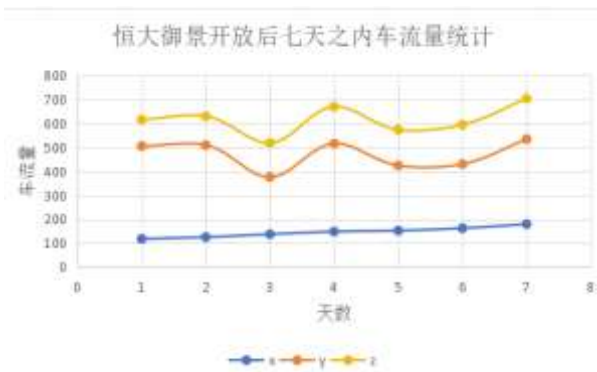


Figure 11 Traffic flow statistic within 7 days after the opening of Hengda YuJing

Note: Traffic flow is defined as the number of vehicles passing through a defined road section per unit time. Therefore, the parameter “z” here is not the sum of “x” and “y”, simply aggregating vehicle counts make no sense.

Derived from the above analysis, the relationship between the road congestion coefficient[5] and road utilization rate[6] during the first seven days following the opening of Hengda Yujing residential area is obtained, as illustrated in figure 12.

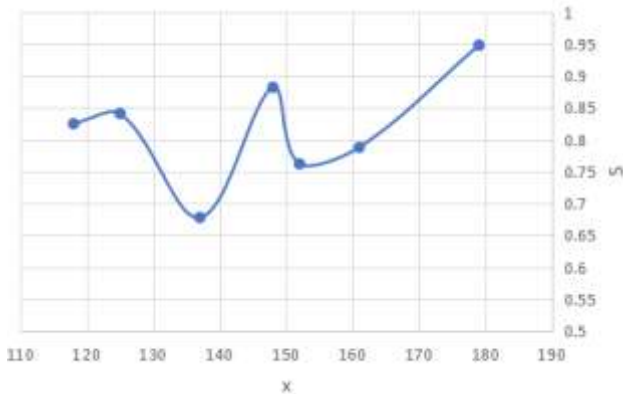


Figure 12 The relationship between the road congestion coefficient and road utilization rate within 7 days after the opening of Hengda YuJing

As shown in the figure above, it can be known that before the opening of the community, the traffic saturation of the community is greater than the critical value, that is, the road traffic is more congested, with the increase of the number of open days, the road traffic flow increases, and the road congestion is slightly improved, but with the continuous increase of the traffic flow at the intersection of the community, the congestion is on the rise.

Based on the results, there are 3 recommendations for the Hengda YuJing neighborhood if the neighborhood is realized to be open:

(1)Optimize the structure of the neighborhood road network and increase the density of the road network. Open neighborhoods is not to remove the wall, but to solve the problem of urban traffic access, divide the city into more neighborhoods of different sizes, more save the limited land area of the urban area and increase the capacity of the road around the neighborhoods with high traffic flow[9].

(2)According to the community road structure planning community open degree and open the number of intersections, and in the community road intersection around the road junction to increase traffic police personnel. Such as Hengda YuJing neighborhood is located around the school, can be opened during the peak school hours to ease traffic congestion, and in Jinyintan Avenue, additional traffic police to enhance

the ability to command, to ensure the safety of students, parents and other personnel.

(3)In view of the opening of the district, the district is no longer closed, the security of the residents is reduced, it should be community entrances and exits from the previous visitor system replaced by face recognition, cloud storage of big data systems, and each household should be installed in the home burglar alarm system[10], security personnel should conduct vehicle command and security patrols at all cell openings ,so that the construction of the district is integrated into the peace and harmony in the construction.

6. Model optimization and evaluation

In the hierarchical analysis method using the target level, criterion level, program level layer by layer analysis, the factors are given different weights, for the unstructured characteristic system for multi-objective, multi-criteria, multi-period evaluation has a better effect, while the problem of data information is less, decision-making when the supervisor of the component is larger. Based on the normal distribution distribution function using the road saturation model, determine the critical value of road saturation, by comparing the critical value, assess the traffic condition of the second channel of the airport of the Jinyintan Avenue, compare the results of the visualization, and give the rationalization proposal, the workload is small and easy to realize, but for the road structure and the internal structure of the district and other factors are easy to consider incomplete.

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