Research on GIS-Based Urban Road Network Congestion Recognition Model

Hai Xiao¹*, Yu Wang², Yuan Zheng², Lu Chen²

¹College of Architecture and Urban-Rural Planning, Sichuan Agricultural University, Dujiangyan, China
²College of Architecture and Urban-Rural Planning, Sichuan Agricultural University, Dujiangyan, China
*Corresponding author’s e-mail: 41228@sicau.edu.cn

Abstract. Traffic congestion has now become one of the most serious urban problems, but the existing research seldom explores the recognition model level of traffic congestion. Taking the central area of Zhonghe Street in Chengdu High-tech Zone as the research area, and mitigating traffic as the basic goal, from the perspective of road network, collect one-week road traffic data of Gaode and use field investigation and big data spatial sampling and other means with GIS spatial analysis methods. A "point"."line"."surface" congestion situation analysis model was established to explore the causes of traffic congestion within the study area. The results show that the main traffic congestion of Zhonghe Street is distributed along Tianfu Avenue in the west, along Zhonghe Avenue in the middle, and the old city area in the northeast. Congestion is unevenly distributed in time and space. It is recommended to carry out targeted optimization planning and transformation of the road network to alleviate traffic congestion and improve the efficiency of road network traffic.

1. Introduction

Traffic is developed with the needs of human’s production and life. Urban traffic is the lifeblood of a city [1]. Congested road traffic seriously hinders the efficiency of the normal operation of the city. It is necessary to fundamentally alleviate the problem of road congestion and increase the load on the road. The efficiency can be optimized from the structure to increase the speed of the vehicle and make the road system smoother [2]. In addition, functional improvements can be made to avoid waste of resources in urban roads and reach the maximum road carrying capacity. Xu Ancheng applied the analytic hierarchy process in the 2012 branch road network evaluation to build an evaluation index system to assess the reasonable status of the road gradation at all levels of the road network in Hangzhou, and put forward decision-making suggestions on the optimization of the branch road network function in Hangzhou [3]. Yang Tao pointed out in 2014 that it is necessary to establish a reasonable road network classification system and adopt a reasonable layout to guide the development of the urban road network system in order to solve the problems of imperfect and unreasonable systems in China’s urban road network. Road network planning needs to be adapted to local conditions and differences. To build a healthy city road system [4], the development of a healthy city and urbanization is inseparable from the healthy development of urban roads [5]. This research attempts to dig the road traffic information from the perspective of big data, uses a congestion recognition model based on road condition data to analyze the current situation and causes of traffic congestion, and proposes optimization suggestions for the road.
network, and strives to alleviate the current congestion in the research area and enhance the road traffic capacity and provide a basis for road network planning.

2. Overview of the study area, data sources and research methods

2.1. Overview of the study area
The spatial area of this study is mainly high-tech zone Zhonghe Street, starting from Century City Road and Renhe Road in the north, Yinglong Road and Laochengren Road in the south, Tianfu Avenue in the west, and Zhongbai Avenue in the east. The research area is about 850hm2. To meet the needs of this research and highlight the research area, the research area chooses the core area of Zhonghe Street and the industrial area between Tianfu Avenue and Fuhe as the objects of congestion identification and road network optimization.

2.2. Data sources
The data used in this study include 1) the road infrastructure information extracted from satellite remote sensing image data of Zhonghe street in 2019 through Google map, such as traffic light installation, traffic signs, road signs setting, lane direction, road grade, lane number. 2) the real-time road condition data of Gaode map in the study area, the area and spatial location of urban land usage information, such as residential land, road construction land, public facilities land and industrial land at the present stage.

2.3. Research methods
The key to the congestion situation recognition model is to clearly show the relationship between traffic demand and supply. The first is to determine whether a road section is congested at a certain moment, and mark its corresponding spatial position in the road network to form a congestion situation data map, then the spatial distribution of congestion elements is carried out from the three dimensions of "point-line-surface" to analyze and discover the causes of congestion. Therefore, a congestion situation recognition model is created to judge and identify the intensity of the urban road network from the perspective of quantitative indicators.

Road network congestion "points" are congestion "points" that indicate the degree of congestion divided into the road conditions map. The road condition information of the study area is intercepted and integrated through the road condition map function of Gaode map, and the road congestion level is sorted and divided. The congestion state of the road section is determined according to the traffic congestion index of this road section.

The road network congestion "line" refers to the specific road in the road network. Congestion "points" have connectivity so that adjacent congestion "points" will have mutual influence. It will cause a chain effect and lead to connection congestion if they are not cleared in time. Therefore, by judging whether adjacent congestion "points" in the congestion "line" are continuously congested, it can be determined whether the road condition of the target road has reached the congestion level. If the start and end points of the two road network congestion "points" are overlapped, it means that a continuous congestion "line" is formed (then the congestion state is consistent). On the contrary, if there is no coincident node, the congestion point is judged as inconsistent congestion state. (In this study, the road section with TCIpoint≥3 is defined as road congestion)

\[
TCIline=r_i(n) = \frac{1}{n} \sum_{i=1}^{n} r(n)
\]

TCIline represents the route congestion discrimination index. ri(n) represents the line congestion intensity, which refers to the congestion degree of the i-th road section at the n-th moment, the larger the value is, the more serious the congestion degree is, and vice versa. r(n) represents this line the congestion degree of the road section (TCIpoint≥3) at the n-th moment.

Road network congestion "surface":
The continuation of congestion "points" leads to the formation of congestion "lines", and the linkage and intersection of "lines" will affect each other and cause "surface" congestion. Firstly, start from the
congestion "point" and judge whether the two-two road sections form a congestion "point" centered on the intersection, then use this point as the fixed point to query whether the adjacent intersection is a congested intersection, and it can be confirmed that the composed area of these congested intersections is a congested "face".

If the congested intersections formed by congestion "points" are continuous, it constitutes a congestion "surface", and vice versa. Set congested intersection is 1, if congested surfaces are overlapped, the more overlap is, the greater the degree of congestion is.

\[
\begin{align*}
TCI_{cross} &= 0 \\
TCI_{cross} &= 1
\end{align*}
\]

(2)

\[TCI_{polygon} = \sum_{x=1}^{y} TCI_{cross}\]

(3)

The value of TCIcross indicates whether a congestion "surface" is formed between congested intersections. TCIpolygon shows the number of repeated layers in the formed congestion "surface". The larger value means the more overlapping layers, which can give greater layers of congestion "faces".

Figure 1. Flow chart of "point", "line" and "surface" road network congestion recognition model.

### 3. Results and analysis

In this research, the personal geographic information system established by ArcGIS is used to input the collected road traffic data of Zhonghe Street, and use the data processing function of the ArcGIS attribute table query calculation and the function calculation function of the Excel table to do classifications and statistics of the congestion elements. Use ArcGIS overlaying analysis, reclassification and other spatial analysis functions to obtain the spatial distribution characteristics of congestion elements and achieve the goal of visualization at the same time. The analysis and visualization functions of the GIS platform are used in this study to identify and display the congestion situation of the urban road network.

#### 3.1. "Points" Analysis of Road Network Congestion

Because the congestion conditions on the road are fluid, the congestion "points" in this study are not the ones in the traditional sense, but the road sections indicated the degree of congestion are divided into the road conditions map, which are regarded as congestion "points". The following is the result of statistical analysis of road condition data (the data is for the peak hours in the morning and evening of the day and for the ordinary time of the day with the traffic normal flow, excluding the sudden decrease in the traffic flow late at night). During peak hours, the main road section is heavily congested. At the same time, the congestion of the secondary road is also more serious. The congestion of the branch road is lighter than that of the main road and the secondary road.

| Road grade      | Total number of sections | Congestion ratio during peak hours | Proportion of congestion |
|-----------------|--------------------------|-----------------------------------|-------------------------|
| Main road       | 25                       | 72.12%                            | 68.23%                  |
| Secondary road  | 106                      | 50.24%                            | 48.11%                  |
| Branch road     | 103                      | 36.15%                            | 31.72%                  |
From the perspective of road conditions at all times, the total traffic pressure in the study area is relatively high. The proportion of congested sections on main and secondary roads has not been decreased significantly, and the proportion of congested sections on branch roads has been decreased. However, compared with peak periods, the congestion situation of all roads has been greatly relieved, and the degree of congestion is relatively low.

The distribution of road network congestion "points" in the study area can be divided into three regions according to east-central-west. The congested area in the west is mainly the east of Fuhe River. There are more congested road sections near the New Century Pavilion, Tianfu Software Park, Jiangtang Park and Guilong Park. The congestion of this area is caused by the traffic concentration of office crowds and leisure crowds. The central part is mainly a dense residential area. There are as many as 49 residential communities in the middle of Zhonghe Street, and there are also densely populated areas, such as Zhonghe School, Zhonghe Primary School, and Xiangxie Shopping Center. Due to the unreasonable road network structure in the central part, the road layout is rather messy, and many road sections have broken ends, which are formed the parking areas. The eastern part is similar with the central part which is affected by the residential area with inevitably larger traffic flows, and the eastern road driving environment is affected by subway construction.

3.2. "Lines" Analysis of Road Network Congestion

Through comparison and statistical analysis, the distribution of congestion "lines" in Zhonghe Street roughly is corresponded to the distribution of congestion "points". Road operation is generally smooth, but the distribution of congestion is relatively large. Many roads are congested and busy. Among 68 routes (for the accuracy of the research content, a road is divided into two routes according to the direction of the lane in a broad sense), 41 routes have a congestion index above 2.5.

The main road congestion in the study area mainly reflects the huge traffic flows in the morning and evening peaks. The reason for the secondary road congestion is that it can’t evacuate the traffic from the main road in time. The traffic backlog causes congestion. The branch road congestion mostly comes from the huge traffic flows in the residential area and the chaos of the branch road itself. According to the judgment, there are 26 congested intersections in the study area, 26 congested areas are formed by using the model. Through overlay analysis, a layer with 38 congestion "surfaces" is generated, which contains 16 of the first-level congestion "surfaces" and 22 of the second-level congestion "faces".

3.3. "Surface" Analysis of Road Network Congestion

Congestion "points" and congestion "lines" affect the formation of congestion "surfaces" to a certain extent. From the points of the congested intersection, the defined intersection congestion range is formed, and the surface-surface overlay analysis is used to form a superimposed congestion "surface". The new congestion area contains the original congestion information.

It can be seen from the figures that the congested area of Zhonghe Street is mainly distributed in the area along the middle section of Tianfu Avenue, the area along the Zhonghe Avenue in the middle of the study area and the area along the Zhongbai Road. Among them, the congestion situation in the area along Zhonghe Avenue and the area along Zhongbai Road is relatively severe, forming a high-level congestion "surface". Both places are traffic flows in the city, where people flow is relatively concentrated. The road system around the congestion surface is imperfect and the road density is insufficient, resulting in the traffic flow cannot be dispersed and concentrated in a fixed area, so congestion is formed.

| Road grade   | Road name               | Congestion Index                               |
|--------------|-------------------------|------------------------------------------------|
| Main road    | Tianfu Avenue           | 3.2 from south to north, 2.83 from north to south |
|              | Kehua South Road        | South to North direction 3, North to South direction 2.33 |
| Secondary road | Zhonghe Avenue       | East to West 3, West to East 2.67              |
|              | Century City Road      | East to West 2, West to East 3                |
Based on the above three congestion characteristics, combined with urban development plans over the years, there are three main reasons for the congestion in the road network system of Zhonghe Street. Firstly, the functional partitions in the study area are too dense, resulting in tidal congestion between residential and work commutes. Secondly, the road network system is not well planned and the microcirculation system is lacked, resulting in systemic congestion of the main roads. Finally, because the study area is one of the two major groups in Tianfu New District, although population gathering has a positive impact on the economic and social development of the economic zone [6]. However, the large influx of population has led to insufficient carrying capacity of the road network system.

| Branch road | Century City South Road | 2.5 from south to north, 3 from north to south |
|-------------|-------------------------|---------------------------------------------|
|             | Laochengren Road        | 3.5 from south to north, 2.5 from north to south |

4. Conclusion

This study uses GIS spatial analysis methods to establish a "point"-"line"-"area" congestion situation analysis model to explore the causes of traffic congestion within the study area and analyze the road network congestion mechanism in the study area. The results show that the road network structure of Zhonghe Street of Chendu Tianfu New District is unreasonable, which is lack of east-west trunk roads and has the uneven distribution of secondary trunk roads and branch roads in the study area. Branch roads are underdeveloped, which has not formed road network microcirculation system, and the intersection design is unreasonable. In view of the above problems, in the road network structure aspects, it is also a practical way to solve the road network congestion problem of road accessibility in addition to the conventional optimization methods.

References

[1] Lei F. (2015) The research on the optimization of urban road networks under the perspective of easing the traffic congestion: Taken the main city area in Xianyang City as an example. Northwest University, Xi’an.
[2] Pengyao Y., Xiaohong C., Xu C. (2010) From Traffic Differentiation and Segregation to Traffic Integration - the Evolution of Urban Road Network Structure Planning. Urban Planning Forum, 2010 (05): 98-104.
[3] Ancheng Xu. (2012) Research on the Improvement and Optimization of Side Road in Hangzhou. Zhejiang University, Hangzhou.
[4] Tao Y. (2013) Healthy Urban Road Network System: The Concept and Essentials. Modern Urban Research., 2013 (8): 91-96.

[5] Xuejuan F., Lei D., Jinchao L. (2019) Research on the Coupling Coordination Relationship Between Urbanization and the Healthy-City Development ——A Case Study of Ningbo. Chinese Journal of Agricultural Resources and Regional Planning., 40 (12): 195-202.

[6] Jie X, Guozhang Z, Pei Z. (2020) Study on Population Distribution and Influencing Factors of Guanzhong-Tianshui Economic Zone Based on GIS. Chinese Journal of Agricultural Resources and Regional Planning., 41 (5): 167-175.