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Research Article

Research on the Supply of Shared Bicycles in Subway Hub Stations-Taking the Subway Station of Zhengzhou People 's Hospital as an Example

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Abstract

In recent years, with the rapid development of shared bicycles, it has played a great role in alleviating urban traffic pressure and facilitating residents to go out to a certain extent. However, while solving the problem of the last kilometer of travel, the uneven distribution of shared bicycles in subway hub stations is becoming more and more serious, which has a certain impact on the quality of residents ' travel. This paper takes the supply of shared bicycles in urban subway hub stations as the research object, and observes and summarizes the characteristics of slow traffic flow near the entrances and exits of subway hub stations in the morning and evening peak hours. On the premise of ensuring the right of way for pedestrians, the supply and demand of shared bicycles in the subway hub station and the configuration of shared bicycles in the surrounding space of the subway hub station are comprehensively considered, and the supply of shared bicycles is predicted by the estimation model and the field data of the subway hub station are investigated, taking the subway station of Zhengzhou People 's Hospital as an example to carry out field research and predict the actual demand and supply of shared bicycles in the subway hub. Finally, the problems existing in the research on the supply of shared bicycles in metro hub stations and possible future research directions are summarized.

Keywords

Subway Station, Shared Bicycle, Demand Forecast, Carrying Capacity, Quantity Supplied

1. Introduction

As a new means of transportation in recent years, shared bicycles are favored by many travelers due to their convenience and high efficiency, and their location distribution is mostly concentrated near subway stations [1]. It often connects the ground and ground traffic in a connection way, which solves the problem that it is difficult to achieve the ' last kilometer ' of accurate transfer between points due to the limited flexibility of the subway, thus affecting the overall operation of the subway and further improving the attractiveness of the subway.

While sharing bicycles brings convenience to people, due to the fluctuation of space-time demand, the distribution of bicycles between regions is unbalanced. On the one hand, the ' oversupply ' of bicycles in some areas has caused the accu-

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mulation of a large number of shared bicycles, increasing the operating costs of the shared bicycle platform; on the other hand, there is a ' shortage of supply ' in some areas, which reduces the convenience and utilization rate of users [2].

In order to accurately predict the demand for shared bicycles in subway hub stations, domestic and foreign scholars have also done a lot of research. For example, Cao Dandan et al. [3] analyzed the influence of time factors and meteorological factors on the demand for bicycles through weather characteristic data information, and used the long-term and short-term memory neural network model to accurately predict the short-term demand for shared bicycles. XU et al. [4] applied the LSTM (Long short-term memory) model to the prediction of the demand for shared bicycles, and constructed a model to effectively predict the demand for shared bicycles. Sun et al. [5] constructed a BP (back propagation) neural network prediction model based on non-negative matrix factorization algorithm, and verified it by using the cycling data of Beijing Mobike on general working days. The results show that the prediction effect of this model is better than that of the traditional BP model. Li Yin [6] put forward some opinions on the demand allocation of shared bicycles, but there is no specific calculation step. Shi [7] and Fan [8] used quantitative analysis to optimize the allocation of shared bicycles, but ignored the impact on pedestrians. Hu Yaqun [9] uses the K-means algorithm to predict the demand for shared bicycles in different rail stations by taking the amount of shared bicycles borrowed and returned as a clustering variable. Li Hao et al. [10] proposed a multi-scale geographically weighted regression model to analyze the density of intersections and geographical points of interest at different spatial scales and their impact on cycling demand. It shows that each demand influencing factor has different scales of action, with time and space differences. Zhang Xinchao et al. [11] integrated LGBM (Light Gradient Boosting Machine), RF (Random Forest), and XGBoost (eXtreme Gradient Boosting) regression models through Stacking to predict the usage of shared bicycles in Washington at a certain time period. Wang Jun [12] proposed a deep learning prediction model based on ConvLSTM (Convolutional Long Short Term Memory) that takes into account both temporal and spatial sequences. It was applied to the test set and compared with the classical temporal LSTM and CNN (Convolutional Neural Network). Wang Fan [13] found that the best algorithm for predicting shared bicycle demand is Boosting integration algorithm. Wang Chaoran [14] proposed a method to improve the accuracy of the user 's shared bicycle travel demand forecast, and a more efficient and reasonable scheduling solution. Wang Mengxue [15] analyzes the operation data of Huizhou in 2022, predicts the demand of each station, determines the number of vehicles used and returned in each time period of each station, and reasonably plans the scheduling scheme. Le Qun [16] combines the characteristics of the site area to determine the main factors affecting the use of shared bicycles, and uses the ridge regression method to predict the demand for shared bicycles.

Through the summary, it is found that the biggest factor affecting the demand for shared bicycles in the subway hub station is time, mainly in the morning and evening peak hours and the general time there is a huge gap. Therefore, on the premise of ensuring the right of way for pedestrians, this paper comprehensively considers the demand forecast of shared bicycles and the calculation method of shared bicycle parking capacity in subway stations, so as to meet the supply demand of shared bicycles in subway hub stations as much as possible.

2. Analysis of Travel Characteristics of Shared Bicycles

2.1. User Characteristics

About 80 % of the bike-sharing users are young people (12-47 years old), while the elderly (47 years old or higher) are very few. This is mainly because shared bicycles are mostly suitable for commuting to bus stations, subway stations and the company 's last mile and short-distance travel; and the shared bicycle is realized by the mobile phone APP through the telecommunications company, which is difficult for the elderly to operate.

2.2. Basic Travel Characteristics

According to the '2023 China's major cities shared bicycle / electric bicycle riding report' [17], statistics and analysis of shared bicycle riding data in Zhengzhou.

(1) The commuter population of shared bicycle riding service in Zhengzhou City accounts for 86 %;
(2) The average distance of single ride of shared bicycles in Zhengzhou City is 1.5 km;
(3) The average riding speed of shared bicycles in Zhengzhou during peak hours is 9.6 km / h.

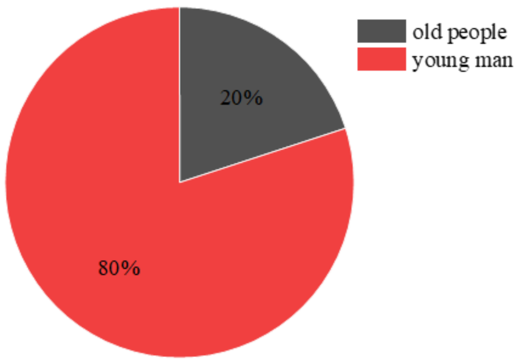

Figure 1. *Age ratio of users.*

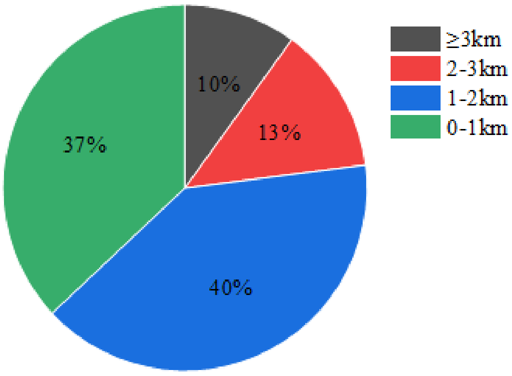

Figure 2. Riding distance ratio.

2.3. Characteristics of Travel Influencing Factors

The change of external weather and environment is the direct factor that affects residents ' demand for bicycle riding. For example, the difference of temperature when going out, the change of weather and other factors directly affect whether people will make the choice of cycling and sharing bicycles, and the demand will change significantly.

However, in general, the factor that has the greatest impact on the demand for shared bicycles is time. In general working days, the demand for shared bicycles in the morning peak and evening peak periods will change greatly from the demand for bicycles in the general time period.

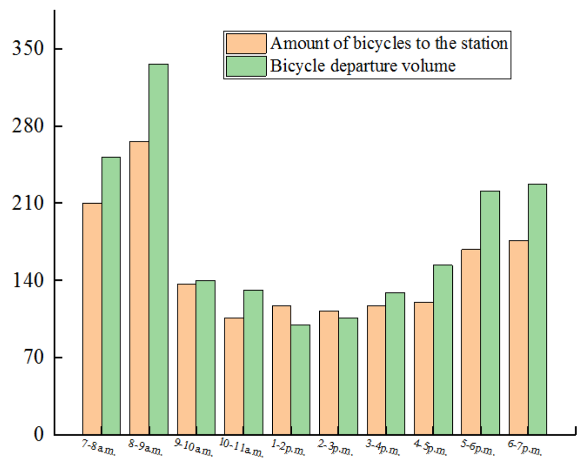

Figure 3. Zhengzhou People 's Hospital subway station throughout the day period of single traffic flow.

3. Model Construction

3.1. Construction Principle

(1) Pedestrian priority principle. On the premise of not harming the interests of pedestrians, the rational allocation of shared bicycles in subway hub stations is sought, while meeting the basic needs of residents ' travel.

(2) The principle of convenient travel. While considering the parking needs of shared bicycles, it is also necessary to meet the normal traffic needs of pedestrians. In the limited space, both walkers and shared bicycle cyclists can facilitate traffic.

(3) Rationality principle. In addition to considering the actual demand for shared bicycles in the subway hub station, it is also necessary to take into account the shared bicycle carrying capacity planned by the subway station.

3.2. Basic Travel Characteristics

The demand supply of shared bicycles in urban subway hub stations is taken as the research object. When establishing the model, the data of the morning and evening peak hours of the general working days of the subway station import and export are selected. Due to the large flow of people in urban public transportation during the morning and evening peak periods, there is a large demand for shared bicycles.

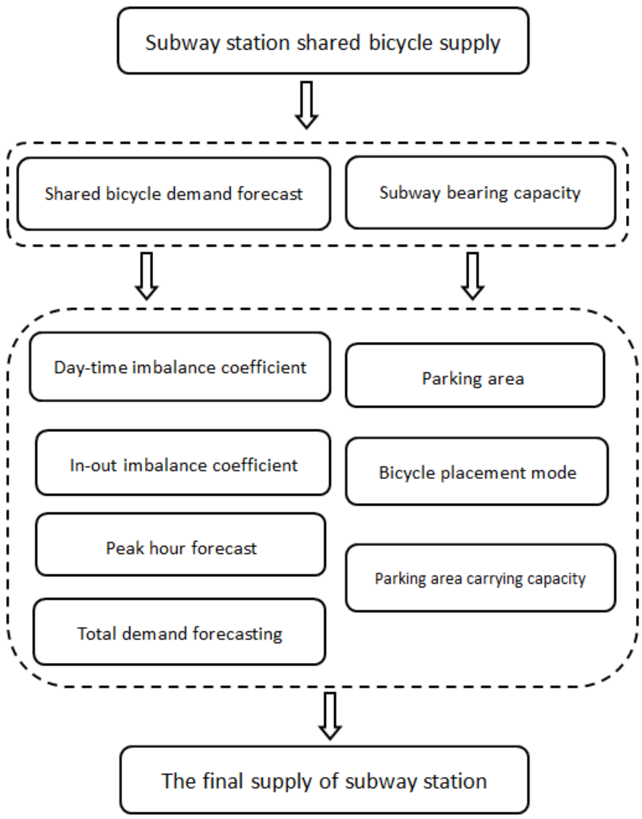

Figure 4. Model calculation flow chart.

The data during this period are used to calculate the daily imbalance coefficient and the in-out imbalance coefficient by using the demand forecasting model of shared bicycles, and the demand for shared bicycles is estimated. Through the proportional characteristics of the flow of people in the bicycle parking area of the subway hub station, combined with the placement of shared bicycles, the parking space carrying capacity estimation model is used to estimate the shared bicycle carrying capacity. On this basis, the values of the two are compared to determine the final supply of shared bicycles in the subway hub station [18].

3.3. Prediction of Shared Bicycle Demand in Subway Stations

In order to predict the demand for shared bicycles in subway stations, that is, the difference between the departure and arrival of shared bicycles. In the process of establishing the model, assuming that the proportion of passengers entering and leaving the station is the same as the proportion of passengers arriving and leaving the station, the imbalance of residents ' arrival time can be used to replace the imbalance of arrival and departure time of shared bicycles.

In the calculation of the flow of people at the entrance and exit of the subway station in the morning and evening peak period and the departure and arrival of the shared bicycles, the time-day imbalance coefficient λ and the in-out imbalance coefficient γ are quoted in hours, and the demand for shared bicycles per hour can be obtained. Among them, λ is the ratio of the number of people leaving the station in an hour to the average number of people leaving the station, and γ is the ratio of the number of people entering the station in an hour to the number of people leaving the station.

The i-th hour shared bicycle predicted departure amount Li:

$$L_i = \bar{q} \times \frac{Q_{oi}}{\frac{1}{n}\sum_{i=1}^{n} Q_{oi}} \tag{1}$$

The i-th hour shared bicycle predicted arrival Di:

$$D_i = L_i \times \left(1 - \frac{Q_{ai}}{Q_{oi}}\right) \tag{2}$$

The time-day imbalance coefficient λ and the in-out imbalance coefficient Y:

$$\lambda_i = \frac{Q_{oi}}{\frac{1}{n}\sum_{i=1}^{n} Q_{oi}} \tag{3}$$

$$\gamma_i = \frac{Q_{ai}}{Q_{oi}} \tag{4}$$

The calculation formula of the predicted demand for shared bicycles in the first hour is as follows:

$$R_i = \bar{q} \times \lambda_i \times (1 - \gamma_i) \tag{5}$$

In the formula:

$\bar{q}$ —The average actual departure per hour of the bicycle;

Qoi —The number of people leaving the station in the i hour;

Qai —Number of people arriving at the i-th hour.

The number of bike-sharing needs in the total time period:

$$A = \sum_{i=1}^{n} R_i \tag{6}$$

R_i is the demand for shared bicycles per hour in the total time period.

3.4. Estimation of Shared Bicycle Parking Space Carrying Capacity

(1) Regarding the division of bicycle parking areas: When planning a bicycle parking space, the size of the parking space should be determined according to the proportion of the number of pedestrians and bicycle occupants in the surrounding area.

The total planned area of shared bicycle parking area is S.

The calculation formula is as follows:

$$S = \frac{BY}{AX + BY} \cdot W \tag{7}$$

In the formula:

W—The total available area of the station;

A—The average required area per person for a pedestrian population;

X—Number of walkers;

B—The average unit area required for shared bicycle parking;

Y—Number of people choosing to ride a bike.

(2) Estimation of parking space carrying capacity

The calculation formula of the bearing capacity configuration of shared bicycles is as follows:

$$N = \frac{(S - rLc)}{kab} \tag{8}$$

In the formula:

S—Total parking area;

r—Channel number;

L—The length of the parking area, that is, the length of the channel;

c—Aisle width;

k—Correction coefficient of tilt degree of shared bicycle placement;

a—The average unit parking area perpendicular to the length of the channel direction;

b—The width of the average unit parking area parallel to the direction of the channel.

3.5. Comprehensive Determination of Supply

After measuring the division of the parking area of shared bicycles at the entrance and exit of the subway station, the demand forecast of shared bicycles in the area and the capacity of shared bicycles in the limited parking area of shared bicycles are obtained. The supply of shared bicycles can be divided into two cases:

(1) If the demand forecast of shared bicycles is greater than the bearing capacity, the bearing capacity of shared bicycles is taken as the final supply of shared bicycles at the subway hub station.

(2) If the carrying capacity of shared bicycles is greater than the demand forecast, the demand forecast of shared bicycles is used as the final supply of shared bicycles at the subway hub station.

The expression is as follows:

$$P = \min\{A, N\} \tag{9}$$

In the formula:

P is the final shared bicycle supply;

A is the demand forecast of shared bicycles at subway entrances;

N is the load capacity of shared bicycles at subway entrances.

4. Zhengzhou City people 's Hospital Subway Station Sharing Bicycle Demand Example

4.1. Overview of the Current Situation of Zhengzhou People 's Hospital Subway Station

At present, there are four subway ports planned for the subway station of Zhengzhou People 's Hospital. Among them, port A, port C and port D have been officially opened, and port B is still under planning and construction.

The daily passenger flow of Zhengzhou People 's Hospital can reach up to 6000 people. The peak period is from 7: 00 to 9: 00, and from 17: 00 to 19: 00. The passengers are mainly commuters, students and patients.

According to the field investigation, it is found that the subway station divides the parking areas of shared bicycles and non-motor vehicles respectively, and measures the parking areas of shared bicycles at the entrance and exit of the subway station of Zhengzhou People 's Hospital.

The measured single column width is 1.8 m.

Table 1. Zhengzhou People 's Hospital subway station import and export bicycle parking area.

Station mouth	A	C	D
Limit stop zone length(m)	21	36	47
Limit stop zone width(m)	1.8	1.8	1.8
Area of limited stopping area(m)	37.8	64.8	84.6
Total area of station mouth(m)	86	147	192

4.2. Zhengzhou People 's Hospital Metro Station Shared Bicycle Demand Forecast

Considering the facilities and adjacent areas near the entrances and exits of the subway station of Zhengzhou People 's Hospital are different, the flow of people in each entrance and exit is also different. Therefore, the current A, C and D ports are analyzed and predicted respectively, so as to determine the overall demand for shared bicycles in the subway station of Zhengzhou People 's Hospital.

The demand forecast of shared bicycles in the subway station A of Zhengzhou People 's Hospital.

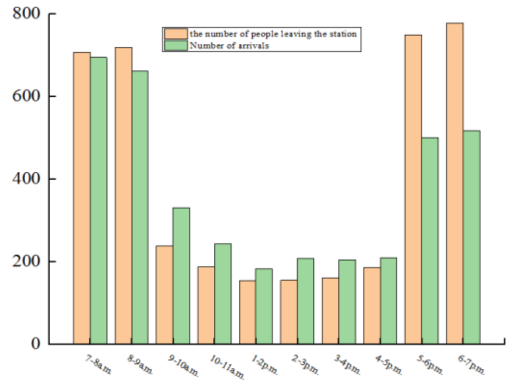

Figure 5. Zhengzhou people 's hospital subway station A population flow.

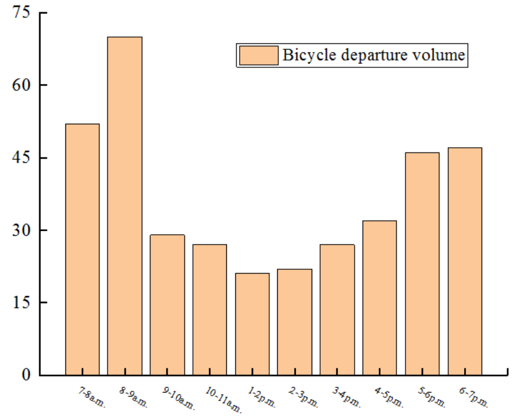

Figure 6. Zhengzhou people 's hospital subway station A all-day bicycle departure volume.

(1) The overall data of the import and export of station A of Zhengzhou People 's Hospital obtained from the survey were statistically analyzed, and the number of people entering the station, the number of people leaving the station and the number of bicycles leaving the station A of Zhengzhou People 's Hospital in general were obtained.

The analysis of Figure 5 and Figure 6 shows that the situation of the evening peak (17: 00-19: 00) conforms to the model hypothesis.

According to the calculation parameters of the model:

$\bar{q}$ =37.3, λ1 =1.84, γ1 =0.66;

λ1 =1.92, γ2 =0.66

λ1, γ1 represents the parameter of 17-18 points;

λ2, γ2 represents the parameter of 18-19 points.

The demand forecast of shared bicycles in the evening peak period of Zhengzhou People 's Hospital subway station A is as follows:

$$R_1 = \bar{q} \cdot \lambda_1 \cdot (1-\gamma_1) = 20(vehicles)$$

$$R_2 = \bar{q} \cdot \lambda_2 \cdot (1-\gamma_2) = 21(vehicles)$$

The total demand is:

$$A = R_1 + R_2 = 41(vehicles)$$

(2) Zhengzhou people 's hospital subway station A import and export parking space bearing capacity estimation

According to the survey of the number of pedestrians and the number of cycling bikes between 17: 00 and 19: 00, it can be found that the number of shared bikes at the subway entrance is too small at this time. If the actual data of the existing number of bikes in this area is used to estimate, it will lead to a large deviation in the research results of this paper. Therefore, in the later calculation, the bike usage Qs (without deducting the number of arrivals) predicted in the demand forecasting model is selected as the data source.

Table 2. *A port parking with pedestrians through the data table.*

time frame	Prediction of bicycle usage (vehicles)	The number of people passing through the sidewalk (people)
17-19	141	1527

Of which:

$$Q_s = \bar{q} \cdot (\lambda_1 + \lambda_2) = 141(vehicles)$$

Table 2 only counts the number of passengers passing between 17: 00 and 19: 00 in the evening rush hour. However, according to the actual running mileage of the subway, in fact, passengers do not appear at a certain time point at the same time, but according to the number of shifts and time intervals of the subway station. When observing the characteristics of outbound passengers, it can be found that the time interval between passengers leaving the subway entrance is basically consistent with the departure interval of the subway (4.5-5min). According to the survey, after 19: 00 pm, there are few shared bicycles at the entrance and exit of the subway, so this paper chooses the data from 17 to 19 as the research object, and divides the value by 24 with 5 minutes as a cycle. The calculation steps are as follows:

Number of walkers:

$$X = \frac{1527}{24} = 64(people/5min)$$

Number of cyclists:

$$Y = \frac{141}{24} = 5.88(people/5min)$$

According to the formula (7):

Of which:

A=0.3m, B=0.9m, W=86m2

The total area of the designed parking spot is:

S= 18.06 m^2

It can be inferred that the existing shared bicycle limited parking area can meet the shared bicycle parking demand.

Through the calculation of the volume of shared bicycles, the average length of shared bicycles is 1.6 meters. When they are placed centrally, the average width is about 0.35 meters. Combined with the parking density of shared bicycles, A = 1.8, b = 0.5. Zhengzhou People 's Hospital Subway Station currently has all planned shared bicycle parking areas, and shared bicycles can be placed vertically, so r is 0.

The width of the limited parking area is 1.8 meters, which satisfies the 90-degree vertical parking of the shared bicycle.

Bring the parameters into Formula (8), S = 37.8m2, r = 0 (there is no channel here)

L=21m, c=0.3m, k=1, a=1.8m, b=0.5m

Calculated: N_1 = 42 (car).

That is, the bearing capacity of the A-port parking point is about 42 vehicles.

Therefore, the total number of shared bicycles in the design parking area of the entrance and exit of Zhengzhou People 's Hospital subway station A is about 42, which can meet the demand of 41 in the evening peak period.

Then the final configuration is:

$$P_1 = \min\{A, N_1\} = 4(vehicles)$$

Similarly, the same method can be used to calculate the demand for shared bicycles at the other two entrances and exits of the subway station of Zhengzhou People 's Hospital.

Table 3. *Zhengzhou People 's Hospital subway station each station entrance supply quantity.*

	demand	load capacity	quantity supplied
A	41	42	41
C	81	72	72
D	106	94	94
total supply P			207

4.3. Final Supply Volume

The demand configuration of shared bicycles in the whole station of Zhengzhou People 's Hospital subway station is as follows:

$$P = 207(vehicles)$$

5. Conclusions

This paper mainly analyzes the supply of shared bicycles in subway hub stations. On the basis of ensuring pedestrian right of way, a calculation model considering the demand of shared bicycles and the capacity of planned parking area in subway hub stations is adopted to solve the problem of supply and demand of shared bicycles in subway stations as much as possible.

The example demonstrates that the model has certain application value for urban construction. Through the model of this paper, the supply of shared bicycles in the subway station of Zhengzhou People 's Hospital is estimated. This article only considers the impact of time factors on the demand for shared bicycles. In the actual situation, the demand for shared bicycles will also be affected by other factors, such as the temperature and weather when traveling will have a direct impact on whether people choose to ride shared bicycles. In the follow-up, the demand and supply of shared bicycles in subway hub stations can be considered under the influence of various factors. According to the prediction of the demand for shared bicycles in subway stations, it can provide a basis for the scheduling of shared bicycles. The supply of shared bicycles is combined with the scheduling of shared bicycles. According to the actual situation of different subway hub stations, the number of shared bicycles in different regions is adjusted, so as to make rational use of shared bicycle resources in a real sense and avoid the idle and waste of economic resources. This will greatly alleviate the pressure of urban public transport travel, but also reduce the degree of traffic congestion. It is a major change for the development of the shared bicycle industry and improve the quality of shared bicycle services. It is of great significance to reduce the operating costs of enterprises.

Abbreviations

LSTM: Long short-term memory
BP: back propagation
LGBM: Light Gradient Boosting Machine
RF: Random Forest
XGBoost: eXtreme Gradient Boosting
ConvLSTM: Convolutional Long Short Term Memory
CNN: Convolutional Neural Network

Author Contributions

Jihua Wang: Data curation, Software, Validation, Investigation, Visualization, Methodology, Writing – original draft.

Yan Chen: Conceptualization, Resources, Formal Analysis, Supervision, Project administration, Writing – review & editing.

Data Availability Statement

Authors are required to provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study.

Please select one sentence to describe the availability of data.

1. The data that support the findings of this study can be found at: https://www.tianqi24.com/zhengzhou/history2022.html
2. The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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Research Field

Jihua Wang: Traffic engineering-1, Highway design/maintenance-2, Pavement design-3, Intelligent Transportation System-4, Transportation safety-5.

Yan Chen: Traffic engineering-1, Highway design/maintenance-2, Pavement design-3, Intelligent Transportation System-4, Transportation safety-5.