2021 6th International Symposium on Computer and Information Processing Technology (ISCIPT) | 978-1-6654-4137-7/21/$31.00 ©2021 IEEE | DOI: 10.1109/ISCIPT53667.2021.00059

Time Prediction of Passing a Congested Road

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***Abstract*-It is very important for navigation software to accurately predict the congestion time, especially in the state of traffic congestion. Therefore, this article is based on the original BPR function, improving the analytic hierarchy process by Fuzzy Theory, and got the modified BPR function to improve the accuracy of the prediction. The specific work is as follows:**

First, we read a large number of relevant literature and determine the factors affecting the degree of road congestion using Delphi method. Then we built the hierarchical analysis model based on fuzzy set theory and got the weight of each factor.

Then, we collected the relevant data of Shanghai, and used the weight of each factor obtained by the AHP model to re-calibrate the parameters of the BPR function, making the improved BPR function more in line with the road conditions in China.

Finally, we use SPSS to do analysis on the GPS data of taxis in Shanghai, and verify the accuracy of our model to predict the passing time of congested roads. It is found that the model can reflect the congestion condition more accurately than the existing models.

Key words⁻Fuzzy-DEMATEL; Analytic Hierarchy Process; BPR Function

I. Introduction

In recent years, the rapid development of navigation software has brought great convenience to people's travel. Navigation software not only helps people plan their routes reasonably on unfamiliar roads, but also has an important function to predict transit time. The prediction of the road condition ahead can enable people to reasonably predict and plan the trip, thus greatly improving travel efficiency, and the realization of this function is supported by big data behind the navigation software. The navigation software collects real-time data such as the speed, position and driving direction of the road by the user's GPS, thereby judging the condition of the road. In addition, the database with a large amount of information owned by the navigation software service provider contains a lot of historical data, providing strong data support for predicting road conditions.

As people pay more and more attention to the value of time, predicting transit time, especially predicting the passing time of congested roads, becomes one of the important purposes of using navigation software. The accuracy of time prediction is a key factor affecting the users ’experience of navigation software. Therefore, navigation software is striving to improve its technology to achieve accurate prediction of transit time.

A. Restatement of the Problem

Since the existing navigation software predicts the road condition ahead only by collecting the user's GPS information, in the case of severe traffic congestion, the software estimate of transit time is not accurate, sometimes even differs greatly from reality, which seriously affects people's travel effectiveness. According to the requirements of problems, our team needs to establish a model for predicting the passage time of the congestion road, collect the relevant data available, and make a more accurate prediction of the time to pass the traffic jam.

B. Overview of Our Work

Based on the consideration of the comprehensiveness and accuracy of the time prediction model, our team established a more accurate time prediction model on congested roads based on the existing BPR function.

First, in order to measure the degree of road congestion, we selected the appropriate influencing factors and obtained ten evaluation indicators, and constructed a hierarchical structure model to measure the degree of road congestion. In the process of system construction, the concept of triangular fuzzy numbers and CFCS defuzzification are introduced into the construction of judgment matrix of AHP, and the influence of subjective factors on the results is eliminated.

After obtaining the weight of each factor on the degree of road congestion, we constructed a time prediction model based on original BPR function. Since our data comes from domestic cities, we have considered the difference between China's traffic situation and the United States based on the original BPR model, and obtained the improved BPR function. Further, we added the weight of each factor in the AHP model to the function, and then obtained the final time prediction model of the congested road.

II. General Assumptions

①The indicators are selected accurately and the indicators are independent of each ot her.

②The linguistic variable is accurate.

③Indicators meet the transferability, including the relationship between strengths and weaknesses.

④Ignore the impact of non-motor vehicles on the road.

III. Symbol Description

Table 1Symbol Description

symbol	unit	meaning
Hi	-----	Language evaluation set i-th evaluation phrase
aij	-----	Judging the i-th row and j-th column of the matrix
ai	-----	Influence factor of each factor
C.I.	-----	Consistency indicator
R.I.	-----	Average random consistency indicator

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DOI 10.1109/ISCIPT53667.2021.00059

C.R.	-----	Consistency ratio
$\lambda_{\max}$	-----	Judging the largest eigenvalue of the matrix
w	-----	Index Weight
t	min	Travel time of the vehicle passing section
t_0	min	Free flight time
Q	n/min	Traffic flow on the road
C	-----	Road section design capacity
α	-----	BPR function parameters
β	-----	BPR function parameters
T	min	Daily average travel time
qi	n	Traffic volume during the i-th period
η_i	min	Time coefficient of traffic volume (the ratio of traffic volume in time period i to daily traffic volume Q)
v	min/km	Driving speed
s	kn	Mileage

IV. Model Establishment and Analysis

A. Establishment of Analytic Hierarchy Model Based on Fuzzy Theory Processing

1) Building a Hierarchical Model

In order to ensure the scientific and rationality of the road congestion evaluation system, we use the literature mining-two-stage literature research method to construct the index system by consulting a large number of relevant literatures. Among them, LI Ruoling pointed out in the "Traffic and Transportation" that the number of large shopping malls nearby, population density, weather conditions have an important impact on the degree of congestion, Wang Yan explained in "The Causes and Countermeasures of Urban Road Traffic Congestion under the New Situation" The traffic flow, traffic density, and the impact of the number of lanes on congestion, Chen Yizhou's "OBD-based urban road intersection traffic congestion monitoring and optimization technology research" analyzed the lane width, the number of intersections, driving speed, vehicle retention time Based on the above-mentioned literature, we finally selected the following 10 indicators to evaluate the congestion situation and calculate the corresponding weights.

Table 2 Influencing factors

Source of influence factors	Numbering	Influencing factor
road conditions	C1	number of lanes
	C2	width of lanes
	C3	number of intersections
traffic efficiency	C4	vehicle flowrate
	C5	speed
	C6	vehicle detention time
	C7	vehicle density
surrounding environment	C8	number of malls
	C9	population density
	C10	weather condition

From the above analysis, various factors affecting the degree of road congestion can be determined, and thus the hierarchical structure model shown in Figure 1 can be established.

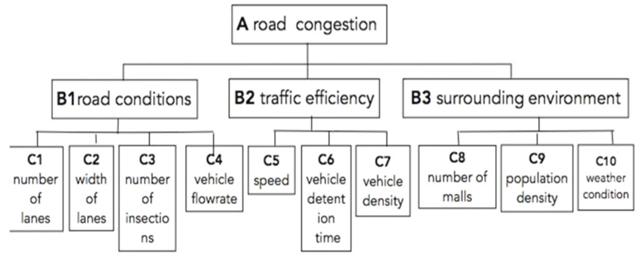

Figure 1 Factors affecting road congestion

2) Using Fuzzy Method

Based on fuzzy theory, we introduce the concept of triangular fuzzy number and CFCS defuzzification into the construction of judgment matrix of AHP, and provide a methodology for the construction of the evaluation index of road congestion degree.

We use fuzzy data based on fuzzy theory to analyze the fuzzy problem of correlation degree, simulate the method of human brain processing fuzzy information, and introduce the subjective judgment of experts by introducing concepts such as fuzzy theory and triangular fuzzy number to eliminate the subjectivity of expert scoring.

We first explain the basic concepts of triangular fuzzy numbers and semantic evaluation sets:

①Triangular fuzzy number means that any element x in the fuzzy set A on thereal number field R can be represented by the membership degree UA(x):R→[0,1](x∈R), which belongs to the fuzzy set UA(x) In addition, the triangular fuzzy number a can be represented by (l, m, r), where 0 ≤ l ≤ m ≤ r ≤ 1, and the membership function is as shown in the formula (1).

$$\left\{ u_A(X) = \begin{matrix} \frac{x-l}{m-l} & l \le x \le m \\ \frac{r-x}{r-m} & m < x \le r \\ 0 & other \end{matrix} \right\} \tag{1}$$

$$\tilde{a} = (l,m,r) = \left(\max\{\frac{i-1}{T},0\}\frac{i}{T},\min\{\frac{i-1}{T},1\} \right)$$

$$i \in [0,1,2 \cdots T]$$

②The language evaluation set refers to a hypothetical language evaluation scale set H = {H0, H1, ..., HT}, where Hi is the i-th evaluation phrase i ∈ {0, 1, ..., T} of the set, H is generally An ordered collection of 5-7 language terms. In this paper, we use "the impact is very large, the impact is large, the impact is small, the impact is very small, no effect" as the language term, according to formula (1) to achieve the conversion from linguistic variables to triangular fuzzy numbers (Table 3).

Table 3 Evaluation method

Language variable	Expert scoring	Triangular fuzzy number	Conversion description
No effect (NO)	0	(0.00,0.00,0.25)	Bring T=4, i=0 into the formula2
Very small impact			Bring T=4, i=1 into

(VL)	1	(0.00,0.25,0.50)	the formula2
Small impact (L)	2	(0.25,0.50,0.75)	Bring T=4, i=2 into the formula2
Great influence (H)	3	(0.50,0.75,1.00)	Bring T=4, i=3 into the formula2
Very large impact (VH)	4	(0.75,1.00,1.00)	Bring T=4, i=4 into the formula2

3) *Using the CFCS Method to Defuzzify*

Quantitative analysis is based on specific data. After linguistic variables and triangular fuzzy numbers are used to integrate information processing with expert evaluation, it is necessary to select appropriate methods to deal with triangular fuzzy numbers, and defuzzify the operation path based on CFCS method. Assuming the triangular fuzzy number f_{ij} =(r_{ij}, m_{ij}, r_{ij}), the complete steps are as follows.

①standardization

$$\Delta_{min}^{max} = r_i^{max} - l_i^{min} \tag{2}$$

$$x_{mj} = \frac{x_{mj} - l_i^{min}}{\Delta_{min}^{max}} \tag{3}$$

$$x_{lj} = \frac{l_{lj} - l_i^{min}}{\Delta_{min}^{max}} \tag{4}$$

$$x_{rj} = \frac{r_{lj} - l_i^{min}}{\Delta_{min}^{max}} \tag{5}$$

②calculate the standard values at both ends

$$x_j^{ls} = \frac{x_{mj}}{1 + x_{mj} - x_{lj}} \tag{6}$$

$$x_j^{rs} = \frac{x_{rj}}{1 + x_{rj} - x_{mj}} \tag{7}$$

③calculate the total standard exact value

$$x_j^{crlsp} = \frac{x_j^{ls} * (1 - x_j^{ls}) + x_j^{rs} * x_j^{rs}}{1 + x_j^{ls} + x_j^{rs}} \tag{8}$$

④calculate the exact value

$$f_{lj} = l_i^{min} - x_j^{crlsp} * \Delta_{min}^{max} \tag{9}$$

4) *Constructing a Judgment Matrix and Assigning Values*

According to the reading of relevant literature, using the Delphi method, the two factors are compared between the two factors, which is relatively more important, and is assigned according to the importance degree by 1-9, and through the fuzzy set processing, the collocation importance scale is as follows:

Table 4 Importance Scale Meaning Table

Importance scale	meaning
1	Two factors are equally important
3	Compared with the two factors, the former is slightly more important
5	Compared with the two factors, the former is obviously important
7	Compared with the two factors,
9	the former is very important The former is extremely important
2，4，6，8	compared to two factors Indicates the intermediate value of the above judgment
reciprocal	If the ratio of the importance of the factors i and j is a_{ij}, then the ratio of the importance of j to i is $a_{ij} = 1/a_{ji}$

$$\begin{pmatrix}
1 & 1 & \frac{1}{7} & 3 & 1 & 1 & \frac{1}{5} & 3 & \frac{1}{9} & 1 \\
1 & 1 & \frac{1}{9} & 3 & 1 & 1 & \frac{1}{5} & 2 & \frac{1}{8} & 1 \\
7 & 9 & 1 & 9 & 7 & 8 & 3 & 9 & \frac{1}{3} & 6 \\
\frac{1}{3} & \frac{1}{3} & \frac{1}{9} & 1 & \frac{1}{3} & \frac{1}{2} & \frac{1}{5} & 1 & \frac{1}{3} & \frac{1}{4} \\
1 & 1 & \frac{1}{7} & 3 & 1 & 2 & \frac{1}{6} & \frac{1}{2} & \frac{1}{8} & 3 \\
1 & 1 & \frac{1}{8} & 2 & \frac{1}{2} & 1 & \frac{1}{4} & 2 & \frac{1}{7} & 1 \\
5 & 5 & \frac{1}{3} & 5 & 6 & 4 & 1 & 6 & \frac{1}{2} & 4 \\
\frac{1}{3} & \frac{1}{2} & \frac{1}{9} & 1 & 2 & \frac{1}{2} & \frac{1}{6} & 1 & \frac{1}{9} & \frac{1}{2} \\
9 & 8 & 3 & 9 & 8 & 7 & 2 & 9 & 1 & 8 \\
1 & 1 & \frac{1}{6} & 4 & \frac{1}{3} & 1 & \frac{1}{4} & 2 & \frac{1}{8} & 1
\end{pmatrix}$$

Then we get the judgment matrix:

After the judgment matrix is obtained, the hierarchical ordering is performed by using the sum method, that is, for the consistency judgment matrix, each column is normalized and approximated by the corresponding weight, and the arithmetic mean of the column vector is obtained as the weight, that is

$$W_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{k=1}^{n} a_{kl}} \tag{10}$$

When performing weight determination, it is necessary to perform consistency check on the judgment matrix. The steps are:

①test consistency indicator *C.I.*

$$C.I. = \frac{max - n}{n - 1} \tag{11}$$

②Look up the table to get the corresponding average random consistency index *R.I.* As shown in Table 3 below.

Table 5 Average Random Consistency Index *R.I.* Table

Order	1	2	3	4	5	6	7	8
R.I.	0	0	0.52	0.89	1.12	1.26	1.36	1.41
Order	9	10	11	12	13	14	15	
R.I.	1.46	1.49	1.52	1.54	1.56	1.58	1.59	

②calculate the consistency ratio *C.R*

$$C.R. = \frac{C.I.}{R.I.} \tag{12}$$

When C.R.<0.1, the matrix can be considered to meet the consistency requirement. If C.R.>0.1, the judgment matrix is corrected.

V. Hierarchical single sorting and verification

The calculation matrix using yaahp software and finally passed the consistency test is shown in Table 5.

Table 6 Level 1 Target Layer Judgment Matrix

A	B1	B2	B3	W_i
B1	1	1/3	3	0.268
B2	3	1	4	0.614
B3	1/3	1/4	1	0.117

In the consistency test, it is obtained, C.R.=0.0707, W=1.0000

Table 7 Second-Level Factor Layer Judgment Matrix: Road Conditions

B1	C1	C2	C3	W_i
C1	1	4	4	0.661
C2	1/4	1	2	0.208
C3	1/4	1/2	1	0.131

In the consistency test, C.R.=0.0516, W=0.2684

Table 8 Two-Factor Layer Judgment Matrix: Traffic Efficiency

B2	C4	C5	C6	C7	W_i
C4	1	3	1/4	1/4	0.123
C5	1/3	1	1/6	1/6	0.069
C6	4	3	1/3	1/3	0.264
C7	4	6	1	1	0.544

In the consistency test, C.R.=0.0903, W=0.6144

Table 9 Two-Level Factor Layer Judgment Matrix: Surrounding Environment

B3	C8	C9	C10	W_i
C8	1	4	3	0.625
C9	1/4	1	1/2	0.137
C10	1/3	2	1	0.239

In the consistency test, C.R.=0.0176,W=0.117，λ=3.0183

1) Hierarchical Single Sorting and Verification

Perform a total ranking, calculate the weight of each factor in each judgment matrix to the highest layer, and synthesize layer by layer from top to bottom. At the same time, a consistency check is also required. The final result is shown in Table 10 below.

Table 10 Hierarchical Total Sorting Table

factor	C1	C2	C3	C4	C5
Weights	0.1772	0.0566	0.0358	0.0764	0.0427
factor	C6	C7	C8	C9	C10
Weights	0.1623	0.3341	0.0735	0.0161	0.0289

In the consistency test, C.R.=0.057, W=1.000

Finally, we get the weight calculation results as shown in the following table11:

Table 11 Weight coefficient

Influencing factor	Weight a
number of lanes	0.1772
width of lanes	0.0566
number of intersections	0.0358
vehicle flowrate	0.0764
speed	0.0427
vehicle detention time	0.1623
vehicle density	0.3341
number of malls	0.0735
population density	0.0161
weather condition	0.0289

A.Traffic Time Prediction Model Based on BPR Function

1) BPR function

The road traffic impedance function refers to the functional relationship between the travel time of the road segment and the traffic load of the road segment. It is the basis of traffic network analysis. The US Federal Highway Administration summarized the relationship between road transit time and road traffic based on traffic surveys on a large number of road sections.

$$t = t_0 * [1 + \alpha * (\frac{Q}{C})^{\beta}] \quad (13)$$

Where: t is the travel time of the vehicle passing section; t0 is the free exit time of the road section; Q is the traffic volume of the road section; C is the road section design capacity; α, β is the parameter to be calibrated, and the US Federal Highway Administration calibrates α = 0.15 , β = 4.0.

2) Improved BPR Function

Considering that the road traffic situation in China is different from that in the United States, the values of α and β should be determined according to actual conditions.

The daily average travel time T can be expressed as the weighted average of the vehicle transit time to the daily traffic volume within one day, is

$$T=\sum_i (t_i * \frac{q_i}{Q}) \quad (14)$$

Substituting the American BPR function (1) into equation (2), and finishing:

$$T=\sum_i [t_0 * \{1 + \alpha * (\frac{q_i}{c})^{\beta}\} * \frac{q_i}{Q}] \quad =t_0*[1+\alpha * \{\frac{Q}{\sum_i \eta_i^{\beta+1} * c}\}^{\beta} \quad (15)$$

Where: $q_i$is the amount of traffic in the i-th time period; η_i is the time coefficient of the traffic volume (the ratio of the traffic volume qi in the time period i to the daily traffic volume Q).

$$\text{make } C' = (\sum_{i=1}^{24} \eta_{\alpha,i}^{\beta+1})^{-\frac{1}{\beta}} * c \quad (16)$$

$$\text{there is } \quad t = t_0 * [1 + \alpha * (\frac{Q}{C'})^{\beta}] \quad (17)$$

Since the road impedance function is greatly affected by other factors, it is necessary to establish an improved road impedance function model to accurately express the urban road impedance. According to the actual situation in China, the factors affecting the road impedance (travel time) are introduced into the BPR model in a linear form, in order to more accurately represent the impedance of the actual road, and the new function is unified into the American BPR function style. We adopt 2019.6.09-2019.6.14 taxi GPS positioning data of Shanghai for analysis, using SPSS17.0 to analyze the actual data, and re-calibrate the parameters such as α, β.

Where: C1, C2, C3..., C10 are the factors affecting the road impedance (travel time) obtained above; a1, a2, a3, ..., a10 are the influence coefficients of each factor; α, β are the final calibration of the model Parameter. The traditional BPR function takes t/t0 as the dependent variable and saturates (Q /C) as the independent variable to describe the image. This requires t0 to determine the function image, and the determination of t0 will increase the complexity of the calculation. Through the improved impedance function, the speed-time-distance relationship v=s/t is used as the dependent variable, and the axis of the road resistance function curve is converted into saturation (Q/C)-unit mileage time (min/ Km), in order to describe the road impedance function more generally, make full use of the collected observation data, and reduce the time complexity of the calculation.

VI. Empirical Analysis and Conclusion

A. Data analysis

In order to ensure better representative of the data and to fully and truly reflect the impedance of the Shanghai road network, we collected the GPS positioning data of 10,000 taxis on the date of 2011.6.09-2019.6.14 for analysis, calculation and calculation.

B. Egression Analysis

In order to verify whether the heuristic path resistance function is applicable to Shanghai, we use SPSS 17.0 to calibrate and compare the US BPR and the improved path resistance function. According to the calibration results, the improved road resistance function is the closest to the scatter plot, which can best reflect the current situation of Shanghai expressway road impedance. Because among the many road influence factors, traffic density, vehicle detention time, the number of large shopping malls around and the traffic volume have a great influence on the road impedance, and can be quantified, so choose the traffic density, vehicle retention time, the number of large shopping malls nearby and the car. As the factors affecting the road impedance, the flow rate is marked as f1, f2, f 3, and f 4 respectively. Through calculation, each parameter is calibrated, where t 0=1.42min/km, and other parameters are listed in Table 12. Substituting each parameter into equation (18) gives a mathematical expression of the improved path resistance function.

$$t=1.42*[1+0.68*(\frac{Q}{C})^{2.48}]$$

Table 12 Function coefficient

US BPR		calibrated parameter values		Improved BPR function					
α	β	α	β	a0	a1	a2	a3	a4	β
0.15	4	0.223	2.037	0.008	0.014	0.021	0.012	0.899	2.482

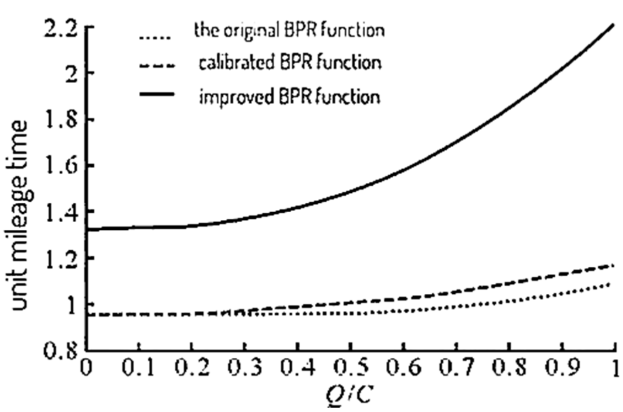

Figure 2 Scatter plot

Figure 2 shows the US BPR function, the recalibrated BPR function, and the improved saturation (Q/C)-unit mileage time(min/km) of the road resistance function. As seen in Figure 2, when saturation When 0, the unit time of the original US BPR function, the recalibrated BPR function, and the improved path resistance function are 0.83, 0.85, and 1.28min/km, respectively. The modified BPR function has the same unit mileage time value at 0 saturation. The mean value of the observed data is close. The deviation between the 0 saturation unit mileage time value and the actual observation value of the other two curves is large. When the saturation is 0.2, the original US BPR function, the recalibrated BPR function, and the unit of the heuristic path resistance function. The mileage time is about 0.8, 0.8, 1.3min/km, and the actual observation value is about 1.5min/km. When the saturation is 0.8, the original US BPR function, the recalibrated BPR function, and the unit mileage of the heuristic path resistance function. The time is about 1,0,0.9,1.8min/km, and the actual observation value is about 2min/km. For the road with low flow rate, that is, when Q/C is small, the improved function can guarantee a certain slope, and 2 kinds The slope of the number curve has almost no change. The heuristic path resistance function based on the BPR function is more accurate and accurate than the traditional road impedance function because it considers the factors such as traffic density, vehicle residence time, the number of surrounding large shopping malls and traffic volume. Reflecting the road impedance of Shanghai.

C. Conclusion

We can establish a hierarchical analysis model by consulting a large number of documents and combining the Delphi method to determine the factors affecting the degree of road congestion. Based on fuzzy set theory, the concept of triangular fuzzy number and CFCS defuzzification are introduced into the construction of judgment matrix of AHP, and the evaluation index of road congestion degree is established. Finally, I collected the GPS positioning data of 10,000 taxis in Shanghai from

November 19, 2009 to November 9.6.14, and improved the track resistance function by improving the traditional BPR resistance function.

$$t=1.42*[1+0.68*(\frac{Q}{C})^{2.48}] \tag{19}$$

Through empirical analysis and comparison with the traditional BRP function, it is proved that the improved BPR function can make a more accurate estimation of the transit time of the car.

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