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RESEARCH ARTICLE

Intelligent Driving Strategy of Expressway Based on Big Data of Road Network and Driving Time

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ABSTRACT An expressway is divided into different road segments according to the entrance-exit toll stations. Based on the driving characteristics of expressways, two methods are proposed to predict the average speed of vehicles on an expressway. One is based on the relationship between the number and the average speed of vehicles on road segments, and the other is based on traffic situation obtained by Baidu, Gaode, and other online maps API. According to the methods, intelligent driving strategies are adopted to satisfy the desired driving time and achieve the driving task successfully. The main principle of the strategies is to adjust the driving route and speed automatically according to the expressway conditions and desired driving time, and to realize the switch of the driving route between the expressway and provincial highway, or national highway and other non-expressway networks. The speed prediction methods and intelligent driving strategies overcome the shortcomings of the existing expressway traffic volume prediction. It has no complex model but is simple, feasible, fast, and practical, which provides an important theoretical basis for the design of expressway intelligent driving systems. The proposed methods exhibits good innovation and practical applications.

INDEX TERMS Expressway, intelligent traffic, road network big data, traffic volume forecast, route optimization.

I. INTRODUCTION

With the sustained and rapid development of society and economy, the number of motor vehicles continues to grow. The number of motor vehicles in China is nearly 400 million in 2021, and there are approximately 300 million vehicles with a growth rate of 4% [1]. Consequently, traffic pressure and road network load are becoming increasingly serious, and the peak duration of traffic flow is prolonged. In particular, during weekends and holidays, the traffic demand for expressways inevitably results in expressway congestion and frequent traffic accidents, which seriously affects the operation efficiency of the expressway. To solve the problem of traffic congestion and strengthen the management and control of expressways, the design of intelligent integrated management and control platforms has become the focus of intelligent transportation research [2], [3], [4].

An expressway is a special transportation route that has the following characteristics. (1) From the starting station to the end station, it can be divided into several road segments according to the entrance-exit toll station, and a vehicle is driving on the road segments sequentially. Moreover, the road segment has a long distance, and there is no switchable route before reaching the next segment; therefore, it has an irreversible driving state. (2) A certain minimum and maximum speed limits are required in different lanes to ensure the efficiency and safety of expressway driving, and the driving speed is high. (3) Once a traffic jam or traffic accident occurs on a certain road segment, it can only drive slowly and wait, and there is no other solution method. (4) Expressway traffic flow has typical dynamic characteristics, such as time-space, nonlinearity, and randomness.

A real-time dynamic route optimization method based on the predictive control principle was proposed by the authors in the reference [5], which takes the travel target time (desired driving time) as the controlled variable and has good practical application value. We apply this method to expressway driving control, and only consider the average driving speed of road segments. Based on the traffic information big data platform of the expressway network [1], Gaode,

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Baidu, and other online map traffic situations, and GIS [6], intelligent driving strategies of expressways based on driving time are proposed. Its main idea is to adjust the driving route and speed automatically according to the expressway conditions and desired driving time, and to realize the switch of the driving route between the expressway and provincial highway, or national highway and other non-expressway networks. Intelligent driving strategy simulates people's driving wisdom, that is, according to different road conditions, driving time, and driving goals, real-time dynamic driving route optimization is taken to avoid congested road segments and traffic accidents, and to ensure that the desired driving time and goals are achieved. Two methods are proposed for traffic flow prediction: the road segment static balance equation method based on expressway network big data and the road segment traffic situation method based on online maps. Based on the driving characteristics of the expressway, the relationship between the number of vehicles and average driving speed of the road segment was established. In fact, in the real world, the more complex the problem is, the more difficult it is to solve it by using complex methods, which may not necessarily achieve the desired results. From the viewpoint of practical applications, we can solve complex problems very well by ignoring the details and using simple and effective methods. For example, Kepler's third law and Einstein's mass-energy equation are good examples, and they use the most concise formula to reveal complex phenomena and solve complex problems. The expressway traffic flow forecasting method and its intelligent driving strategy have no complex model in this study, and the calculation is fast and concise, which meets the actual needs of travelers and has a good application value.

The remainder of this paper is organized as follows. Section II discusses literature review. Section III introduces the mathematical description, conceptual definition of the expressway network, and lemma for the research. Section IV discusses the relationship between traffic flow and driving speed on the road segment. Section V presents the prediction methods for the traffic flow and driving speed on road segments. Section VI introduces the intelligent driving strategy. Section VII verifies the proposed model and discusses the results. Section VIII provides a summary of this study.

II. LITERATURE REVIEW

At present, most of the researches on expressways are the prediction of various traffic parameters and traffic conditions of expressways, and providing reference information for the travel of expressways, but there is a lack of research on intelligent driving strategies. For expressway traffic flow forecasting, it can be roughly divided into the following four types of research methods: models based on statistical methods, models based on nonlinear theory, models based on machine learning methods, and other prediction methods.

Yang et al. [7] selected several representative, statistical models and machine learning models to analyze the influence of periodic component on short-term speed prediction. Dong et al. [8] used an ARIMA (Autoregressive Integrated Moving Average) model for the traffic flow prediction. Gong et al. [9] applied Kalman filtering method to predict short-term traffic volume. Carlson et al. [10] used variable speed limits to study on local feedback-based mainstream traffic flow. Chen et al. [11] provided deep learning method for the traffic flow prediction. Hou et al. [12] studied long-term traffic flow prediction under big data. Zheng et al., Zhao et al., Ma et al., and Chen et al. [13], [14], [15], [16] considered the LSTM (Long Short-Term Memory) networks for short-term traffic flow prediction. Wang et al. [17] researched on highway traffic flow state identification by ensemble learning Method. Except for the traffic flow forecasting, sensor placement problem, traffic speed, traffic density, congestion index and prediction, traffic saturation, traffic state estimation, real-time traffic surveillance, and other parameters are studied [18], [19], [20], [21], [22], [23], [24], [25], [26], [27]. Chen et al., Khosravi et al., and Shi et al. [28], [29], [30] studied the technology of vehicle detection and human-vehicle interaction assisted driving and navigation on ordinary roads.

According to the current research methods, there are mainly the following shortcomings. (1) The influence relationship between the previous road segment and the next road segment is not taken into account, such as the time series method represented by autoregressive integrated moving average mode (ARIMA). (2) Short-term traffic flow forecasting has difficulty reflecting the average speed of a road segment over a period of time, such as the LSTM neural network model. (3) Some models are only suitable for traffic volume prediction in a certain period of time, such as the KNN (K Nearest Neighbors) model for low peak traffic volume forecasting and Markov chain model for peak traffic volume prediction; etc. (4) Some models are complex. Because of the low accuracy of the model and lack of training data, the prediction accuracy is not high, and they cannot reflect the dynamic characteristics of expressway traffic volume and lack practical application value.

Generally, the existing methods are lack of practicality, and the method proposed in this paper is simple, effective and practical.

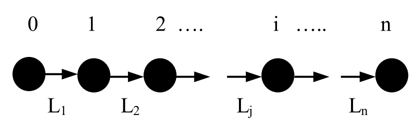

FIGURE 1. Stations and segments of expressway.

III. CONCEPT, DEFINITION, AND LEMMA

To discuss the methods in this study, some of the concepts and lemma involved are defined as follows. Fig.1 shows a schematic diagram of a one-way expressway, where i represents a certain entry-exit toll station, 0 represents the starting station, and n represents the end station. L_j represents the length of the road segment between the two adjacent stations, and TL represents the total length of the expressway:

$$TL = \sum_{j=1}^{n} L_j \tag{1}$$

Definition 1: Origin-Destination matrix, ODM

The OD matrix sorts all traffic zones by rows (starting point area) and columns (destination area). The row represents the starting station, the column represents the end station, and the matrix element represents the OD point pair from the starting station to the end station.

Definition 2: Length OD matrix of expressway, denoted by LM. Length OD matrix describes the distance relationships between road segments. As shown in Fig.2, a LM is described as follows:

O/D	1	2	3	………..	n
0	L_1	L_1+L_2	L_1+L_2+ L_3	…	TL
1	0	L_2	L_2+ L_3	………	TL-L_1
2	0	0	L_3	…. ………	TL-L_1-L_2
.	.	.	.	. . .	
n-1	0	0	0	…………..	L_n

FIGURE 2. **Structure of LM.**

where the element of the matrix represents the length of the road segment from station i-1 to station j, which is expressed as the upper triangular matrix of n ∗ n. i, j=1, 2, ...n.

Definition 3: Road segment length OD matrix of expressway, denoted by RM. The road segment length OD matrix describes the distance relationships between adjacent road segments.

O/D	1	2	3	………..	n
0	L_1	0	0	………..	0
1	0	L_2	0	…………….	0
2	0	0	L_3	…. …….	0
.	.	.	.	. . .	
n-1	0	0	0	…………..	L_n

FIGURE 3. **Structure of RM.**

A RM is described as shown in Fig.3. Where the element a_{ij} represents the length of the road segment from station i-1 to station i, and the other elements are 0, which is expressed as the diagonal matrix of n ∗ n.

The relationship between matrix LM and RM is as follows:

$$\mathrm{RM} = \mathrm{LM} * I \tag{2}$$

where I is the unit diagonal matrix.

Definition 4: Time definition, unit: h.

Desired time or target time (t_d): the driving time set by the driver from the departure to the destination, and it is generally determined by experience or according to the requirements of the travel task. Road conditions, weather and other factors should be considered when t_d is determined. This time did not include rest time.

Estimated driving time (t_p): the driving time estimated by the number of vehicles on the road segment.

Theoretical driving time (t_t): the driving time obtained by an optimization calculation based on the desired time.

Definition 5: Speed definition, unit: km/h.

Theoretical driving speed (V_t): the speed determined by an optimization calculation or experience.

Enabled driving speed (V_e): the speed obtained by using the Gaode or Baidu online map. The Gaode or Baidu online map can provide real-time driving speed and congestion rates of roads in a certain area, which is also called the road traffic situation.

Predicted driving speed (V_p): the speed estimated by the number of vehicles on the road segment.

Maximum speed (V_h): the maximum speed limited by the segment of the expressway.

Minimum speed (V_l): the minimum speed limited by the segment of the expressway.

Real driving speed (V_r): the current driving speed of a vehicle.

Under normal driving conditions, the relationship between the aforementioned speeds is as follows:

$$V_l \leq V_t \leq V_p \leq V_r \leq V_h$$

Lemma Based on Theorems 1, 2 and lemma1 in the reference [5], the following lemma can be obtained.

For a given expressway, if the length (L_i) of each road segment from the starting station to the end station is known and the desired time (t_d) is set, the minimum theoretical average speed of each road segment can be solved by using the following formula:

$$V_{ti} = (m \cdot \sqrt{L_i}) / \sum_{i=1}^{n} \sqrt{L_i} \tag{3}$$

where $L = \sum_{i=1}^{n} L_i$

$$\vec{V} = \frac{\mathrm{L}}{t_d}, m = n * \vec{V}$$

and n is the number of road segments, i=1,2, ... n.

IV. RELATIONSHIP BETWEEN TRAFFIC FLOW AND DRIVING SPEED ON ROAD SEGMENTS

A. RELATIONSHIP BETWEEN THE NUMBER AND THE SPEED OF VEHICLES

Taking a one-way expressway with three lanes as an example, as shown in Fig.4. V_h is the max limited speed, and V_l is the min limited speed.

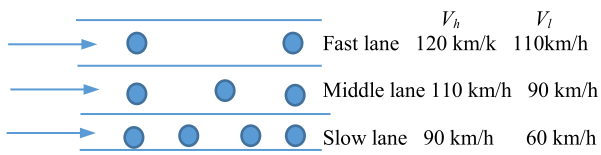

FIGURE 4. **Lane and speed of expressway.**

When the speed is greater than 100 km/h on an expressway, the safe distance is greater than 100 m. When the speed is below 100 km/h, the safe distance can be appropriately reduced; however, the minimum distance should not be less than 50 m. Generally, when the speed is above 60 km/h, the safe distance can be equal to the driving speed.

We assume that the safe distance SD on an expressway is equal to the value of driving speed:

$$\mathrm{SD} = V(m) \tag{4}$$

Theoretically, assuming that the traffic flow of the road segment is equally distributed to each lane, the number of one-way lanes is N, the road segment length is L (km), and the average vehicle length is CL (m). The approximate relationship between the estimated driving speed (V_p, km/h) and the number of vehicles (Num) is obtained.

$$(\mathrm{SD} + \mathrm{CL}) * \mathrm{Num} = N * L * 1000$$

$$SD = \frac{N * L * 1000}{\mathrm{Num}} - \mathrm{CL(m)}$$

$$\text{From(4)}, \quad V_p = \frac{N * L * 1000}{\mathrm{Num}} - \mathrm{CL(km/h)} \tag{5}$$

$$\text{and} \quad V_p \leq 120(\mathrm{km/h}) \tag{6}$$

As shown in Fig.5, the proportion of small cars on the expressway is the largest, and the length of small cars is generally between 3.8 m and 4.3 m, so we can get the value of CL: CL= 4 m.

FIGURE 5. Vehicles on the expressway.

For example, if there are 30 vehicles with a length of 1km (three lanes, with an average of 10 vehicles per lane), the estimated speed is:

$$V_p = \frac{3 * 1 * 1000}{30} - 4 = 96(\mathrm{km/h})$$

If the number of vehicles on a road segment is known, the average driving speed of the road segment can be predicted. Equation (5) is simple, effective, and practical, and the driving speed is inversely proportional to the number of vehicles. This is verified by the data of reference [1], and the results are correct.

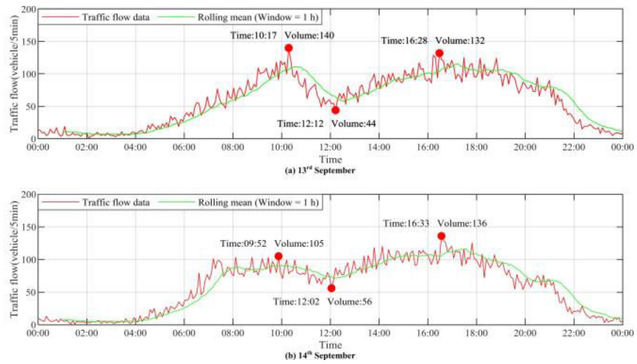

FIGURE 6. Periodicity of traffic flow.

B. PERIODICITY AND TREND OF TRAFFIC FLOW

According to research results in the literature [1], [3], expressway traffic flow is periodic. The traffic flow at the same time every day is similar. For example, as shown in Fig.6, the change of traffic flow on September 13th and 14th is basically the same, with a peak time at about 10:00 and 16:00.

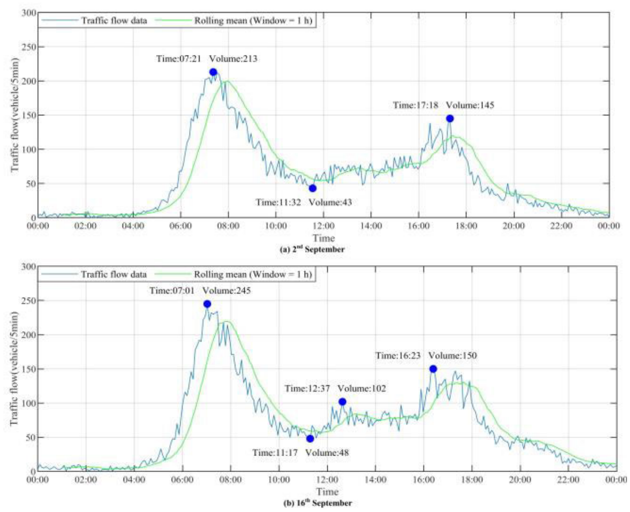

FIGURE 7. Trend of traffic flow.

There exists a trend in expressway traffic flow. Fig.7 shows that September 2 and September 16 are Sundays, the traffic flow on Sunday is generally greater than that on other days, the traffic peak is around 8 o'clock, and the changes of traffic flow on the two Sundays are basically the same.

The periodicity and trend of traffic flow provide an important reference for traffic flow prediction and real-time driving route optimization.

V. PREDICTION METHODS OF TRAFFIC FLOW AND DRIVING SPEED ON ROAD SEGMENTS

Since 2017, the design and implementation of a big data platform for expressway traffic information in China have been completed. Based on expressway driving characteristics and the traffic situation provided by road network big data and Gaode, Baidu, and other online maps, we propose the

TABLE 1. Time correction factor.

Time (minute)	0	5	10	……	1440
Time factor	d_1	d_2	d_3		d_{288}

following two types of methods for the prediction of traffic flow and driving speed on road segments.

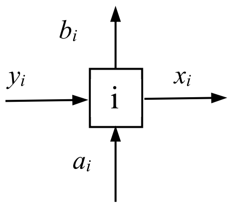

FIGURE 8. Traffic flow of station i.

A. EQUILIBRIUM EQUATION OF TRAFFIC FLOW AT TOLL STATIONS

As shown in Fig.8, for station i, y_i represents the number of vehicles inputting from the previous station i-1, x_i represents the number of vehicles outputting to the next station i+1, a_i represents the number of new vehicles entering from another road, and b_i represents the number of vehicles leaving from the station to other roads.

For one-way expressway traffic flow, the dynamic equilibrium equation of traffic flow exists at a given time Δt:

$$\Delta y_i + \Delta a_i = \Delta x_i + \Delta b_i \tag{7}$$

$$\frac{dx}{dt} = \frac{dy}{dt} + (\frac{da}{dt} - \frac{db}{dt}) \tag{8}$$

Integrate (8):

$$x + c_1 = y + c_2 + (a + c_3 - b - c_4)$$

$$x = y + a - b + (c_2 + c_3 - c_4 - c_1)$$

$$\text{Let}: \quad d = (c_2 + c_3 - c_4 - c_1)$$

$$\text{Then}: \quad x = y + a - b + d \tag{9}$$

Equation (9) can be regarded as a static equilibrium equation. At time t, x represents the number of vehicles on the next segment, y represents the number of vehicles on the previous segment, a represents the number of vehicles entering the station, b represents the number of vehicles leaving the station, and d is a time correction factor.

According to the periodicity and trend of the traffic flow, the data analysis shows that the correction factor d is almost unchanged for the same day at a given time. Taking 5 min as the time unit and using one-day historical data, 288 sets of data were obtained for one day. For a given road segment, a, b, x and y are already known, and the time correction factor d can be estimated using Eq. (9), as shown in Table 1.

Using the historical data of the previous year, a time correction factor table was established every day, and the total time factor tables were 360 for one year. The following method is used to calculate the time correction factor at the current time in this year. For a given time t, judging that it belongs to which time interval according to the time correction factor table, and the time correction factor d at the time is calculated by using linear interpolation or parabola interpolation method.

At the starting station, i = 0, $a_0 = b_0 = 0$, $x_0 = y_0$;at the end station, i = n, $b_n = y_n$, $a_n = x_n = 0$.

B. PREDICTION METHOD BASED ON STATIC TRAFFIC FLOW EQUILIBRIUM EQUATION

1) SINGLE EXPRESSWAY, NO EXPRESSWAY INTERSEGMENT

As shown in Fig.9, according to the network management system of the expressway toll, at a certain time t, the number (a_i) of vehicles entering from other roads, number (b_i) of vehicles leaving to other roads, and number (x_0) of vehicles entering the expressway from the starting station are all known, and it is necessary to solve the number (x_i) of vehicles outputting from station i.

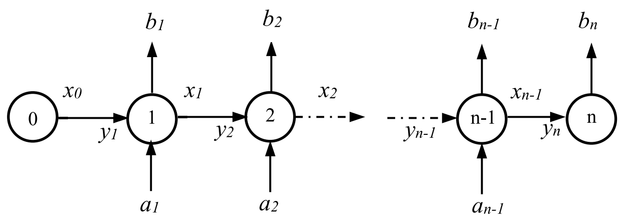

FIGURE 9. Abstract diagram of traffic flow on expressway.

Only the number of vehicles on the road segment is considered. According to Equation (9), $y_i = x_{i-1}$, and there is a static equilibrium equation at each station:

Station 1: $x_0 + a_1 + d_1 = x_1 + b_1$ $x_1 = x_0 + a_1 + d_1 - b_1$

Station 2: $x_1 + a_2 + d_2 = x_2 + b_2$ $x_2 - x_1 = a_2 + d_2 - b_2$

Station 3: $x_2 + a_3 + d_3 = x_3 + b_3$ $x_3 - x_2 = a_3 + d_3 - b_3$

……………………………………………………………

Station n-1: $x_{n-2} + a_{n-1} + d_{n-1} = x_{n-1} + b_{n-1}$

$x_{n-1} - x_{n-2} = a_{n-1} + d_{n-1} - b_{n-1}$

Denoted: $c_1 = x_0 + a_1 - b_1 + d_1$

$c_2 = a_2 + d_2 - b_2$

$c_3 = a_3 + d_3 - b_3$

……………………………………………………………

$c_{n-1} = a_{n-1} + d_{n-1} - b_{n-1}$

Then:

$x_1 = c_1$

$x_2 - x_1 = c_2$

$x_3 - x_2 = c_3$

……………………………………………………………

$x_{n-1} - x_{n-2} = c_{n-1}$

$$\text{Denoted}: X = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ . \\ . \\ x_{n-1} \end{bmatrix} \quad C = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ . \\ . \\ c_{n-1} \end{bmatrix}$$

$$A = \begin{bmatrix} 1 & 0 & 0 & . & 0 \\ -1 & 1 & 0 & . & 0 \\ 0 & -1 & 1 & . & 0 \\ . & . & . & . & . \\ 0 & 0 & . & -1 & 1 \end{bmatrix}$$

$$\text{Then}: \quad A^{*}X = C$$
$$X = A^{-1} * C \tag{10}$$

Equation (10) can be used to calculate the current number of vehicles driving on each road segment, and the initial time (t=0) is calculated from zero o'clock every day.

2) CASE OF EXPRESSWAY INTERSECTION

As shown inFig.10, there is an intersection of two expressways between station i-1 and station i, where u is the number of vehicles from another expressway and v is the number of vehicles traveling to another expressway.

We know:

$$x_{i-1} \neq y_i$$
$$y_i = x_{i-1} + u - v \tag{11}$$

At a certain time t, the values of u and v can be obtained from the expressway network big data; therefore, the estimation of the number of vehicles on the road segment is divided into two parts:

(1) From station 0 to station i-1, it is calculated using (10).

(2) From station i to station n-1, y_i should be calculated first using (11), and then calculated using (10).

If the number of vehicles on the road segment is known, the estimated average speed of the road segment can be calculated using (5).

The characteristics of the model are as follows. (1) The static traffic flow equilibrium equation is used to estimate the number of vehicles on the road segment with the aid of a time correction factor; (2) The time correction factor needs to be obtained by historical data analysis, and time is discrete; (3) The algorithm is simple, the data is convenient and the real-time is strong, and the number of vehicles in each segment of the expressway can be predicted at one time.

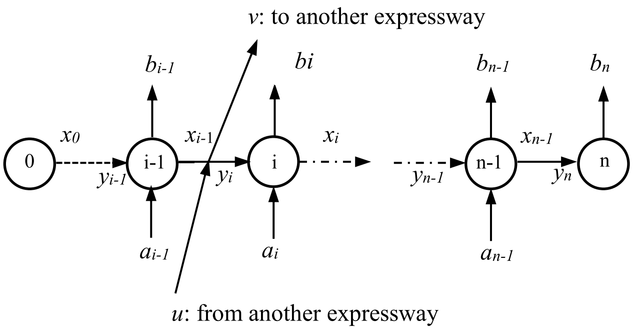

FIGURE 10. Abstract diagram of traffic flow with expressway intersection.

TABLE 2. Speed and weight.

The current situation	The range of speed	Taking a value(km/h)	Weight coefficient
Green: fast	$90 \le V_p \le 120$	$v_1 = 110$	k_1
Yellow: slow	$60 \le V_p < 90$	$v_2 = 80$	k_2
Red: congestion	$40 \le V_p < 60$	$v_3 = 50$	k_3
Crimson: serious congestion	$20 \le V_p < 40$	$v_4 = 30$	k_4

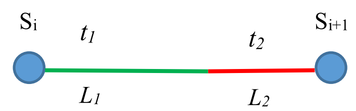

FIGURE 11. Case of congestion.

C. PREDICTION METHOD BASED ON TRAFFIC SITUATION

Based on Baidu, Gaode, and other online maps API, we can obtain the general road traffic situation, including the current driving speed. For expressways, because the length of the segment is relatively longer, the current traffic situation of the segment can only be displayed by road segment color, including green (fast), yellow (slow), red (congestion) and crimson (serious congestion). Because the average driving speed of the entire road segment cannot be obtained, we must attempt to obtain the average driving speed of the entire road segment. According to the characteristics of the expressway traffic situation, the speed weight method is used, as shown in Table 2.

$$\text{Weight coefficient}: \ k_i = \frac{L_i}{L} \tag{12}$$

where L_i is the road segment length with a given color, and L is the total length of the road segment.

The average speed:

$$\vec{v} = v_1 * k_1 + v_2 * k_2 + v_3 * k_3 + v_4 * k_4 \tag{13}$$

As shown in Fig.11, if the congested segment is near the end of the segment, the relationship between the driving time of the congested segment and the driving time of the unblocked segment should be considered, and deciding whether the congested segment should be considered or it should not be considered.

If $\frac{L_1}{V_1} > \frac{L_2}{V_2}$, or $t_1 > t_2$ then ignoring the congestion segment (L_2)

$$\text{If } \frac{L_1}{V_1} \le \frac{L_2}{V_2}, \ \text{or } t_1 \le t_2$$

then setting time t, which is the time spent to the congestion segment:

$$V_1 * t + L_2 - V_2 * t = L_1 + L_2$$
$$t = \frac{L_1}{(V_1 - V_2)} \tag{14}$$

$$L_1' = V_1 * t \tag{15}$$
$$L_2' = L_2 - V_2 * t \tag{16}$$

If $L_1' > L$ or $L_2' \leq 0$ then ignoring the congestion segment (L_2). This means that the congested segment disappears gradually when the vehicle runs from station i to station i+1. Otherwise, the average speed is calculated by replacing L_1, L_2 with L_1' and L_2' in (12) (13).

The calculation process is as follows. (1) Calling the Baidu API to obtain the names of each toll station on the expressway; (2) Obtaining the longitude and latitude coordinates of each toll station; (3) Obtaining the traffic situation of the required road segment and obtaining the color raster data of the road segment; (4) Using GIS to convert the raster data into vector data to obtain the length of the corresponding color segment; (5) Using (12) and (13) to calculate the average speed of the road segment.

The characteristics of the model are as follows. (1) The characteristics of the expressway traffic situation are taken to calculate the average driving speed of the road segment; (2) It does not require the model, the existing platform is used, and the prediction accuracy is high.

Of the above two methods, the first method has the advantage that the number of vehicles on each road segment can be obtained simultaneously, and the disadvantage is that it requires a dynamic correction factor and the accuracy rate depends on the correction factor. The advantage of the second method is that it obtains data according to the existing navigation map platform, and it is fast and convenient. The disadvantages are color recognition and proportion calculation. These two methods have their own characteristics, advantages, and disadvantages, and they can be used in different situations.

Compared to other methods, these methods are simple and practical, and can better reflect the complex time-space relationship of expressway traffic flow. By using simple and effective methods to solve complex problems, they offer good innovation.

VI. INTELLIGENT DRIVING STRATEGY

The basic principle of the intelligent driving strategy is to take the desired driving time as the controlled target (controlled variable), and automatically adjust the route and speed according to the expressway situation and driving time. The switch of the driving route among expressways, national highways, provincial highways, county highways, and other non-expressway networks is realized to satisfy the driving target time.

A. CALCULATION AND STRATEGY AT THE TIME OF DEPARTURE

Step 1: Determine the initial parameters

OD matrix of the expressway: LM, RM.

The length L from the departure to the destination, and road segment length L_i.

The desired time, t_d (h), does not include the rest time. We can consider congestion time and increase the desired time appropriately to ensure that there is sufficient time to complete the driving task.

Step 2: Calculate the theoretical lowest speed of the first road segment using (3), V_{t1}.

Step 3: Calculate the estimated speed of the first road segment using one of the above two methods, V_{p1}.

Step 4: Judge whether the expressway is drivable or not

(1) It is drivable

For the first road segment of the expressway at departure, if $V_{p1} \geq V_{t1}$ and there are no traffic accidents on the segment, we can get on the expressway and start the high-speed journey from the station.

(2) It is not drivable

As shown in Fig.12, for the first road segment of the expressway at departure, if $V_{p1} < V_{t1}$ or there is a traffic accident on the segment, we cannot get on the expressway. We should only choose other road networks, and we get on the expressway again at the next station to avoid the congested road segment.

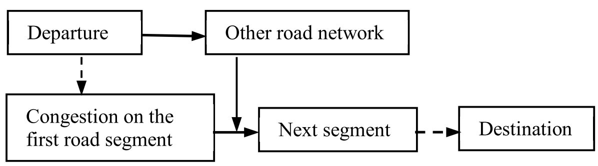

FIGURE 12. Traffic situation of expressway (1).

For the driving strategies of other road networks, based on the method introduced in the reference [5], the theoretical maximum driving time of the segment is taken as the desired driving time of the other road network, and the real-time dynamic driving route is optimized.

B. CALCULATION AND STRATEGY IN THE DRIVING PROCESS

When vehicles are already running on the expressway, and one of the characteristics of the expressway is that regardless of the current road condition, the segment must be finished until to the next segment. When the road segment is nearly finished, the road condition on the next segment should be judged, and it should be decided whether the next segment is drivable. If it is drivable, we can continue to drive on the expressway; if it is not drivable, we should choose to get off the expressway, take another road network, and get on the expressway at the next station again, as shown in Fig.13.

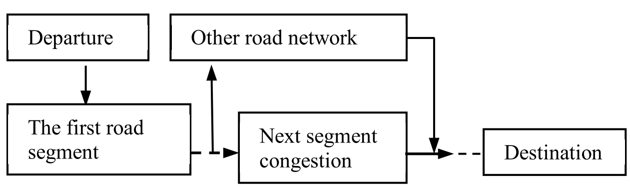

FIGURE 13. Traffic situation of expressway (2).

The detailed process is as follows.

(1) Calculate the driving time t_0, and obtain the remaining time, $t_r = t_d$ - t_0.

(2) Depend on the remaining time, the minimum theoretical driving speed V_t and maximum theoretical driving time t_t of the remaining segments of the expressway are recalculated.

(3) Calculate the estimated average speed V_p and estimated travel time t_p for the next segment according to the expressway condition.

(4) Based on the method in the reference [5], the driving time t_s on other road networks is calculated according to the traffic situation.

(5) If $V_p \geq V_t$, we can continue to drive on the expressway. If $V_p < V_t$ and $t_p > \varepsilon * t_t$ and $t_s < t_t$, we should choose to get off the expressway.

where $\varepsilon \geq 1$, generally ε =1.1∼1.5, which is called the time tolerance coefficient, representing the allowable congestion time.

(6) If $V_p < V_t$ and $t_p \geq \varepsilon * t_t$ and $t_s > t_t$, it indicates that although the expressway segment is congested, other road networks are also congested and do not meet the driving requirements. In this case, according to the principle of expressway priority, the driver continues to drive on the expressway.

C. ANALYSIS OF DRIVING TIME CONTROL

When driving on the current road segment, the driving speed can be increased as much as possible, but it does not exceed the speed limit. Thus, it can shorten driving time, and provide ample time to overcome various road conditions.

(1) If a traffic accident occurs on the next road segment ahead, the vehicle must stop driving. According to real-time road situation data, the estimated accident handling time t_w (waiting time) is obtained. According to the above method, the theoretical driving time t_t of the segment and estimated driving time t_s of other road networks can be calculated.

If $t_w + t_t > \mu * t_s$, we should choose to get off the expressway and avoid the segment with a traffic accident. where μ =1.1 ∼ 1.5, which is determined by the driver based on experience and reflects the allowable waiting time for the driver. Otherwise, although there is a traffic accident, we can still choose to drive to the next road segment.

(2) From departure to destination, sometimes it takes more than one expressway to be used, and it must turn to another expressway until it reaches the destination. We calculate the driving time t_0 on the current expressway, and obtain the remaining time, $t_r = t_d$ - t_0. The time t_r is taken as the new desired driving time on the new expressway, the new related OD matrixes are obtained, and the driving strategy is the same as the previous strategy of the previous expressway.

VII. CASE AND SIMULATION

A. VERIFICATION OF TRAFFIC FLOW PREDICTION METHODS OF ROAD SEGMENT

1) METHOD OF STATIC TRAFFIC FLOW EQUILIBRIUM EQUATION

As shown in Fig.14, there is an expressway, including three stations and three road segments. Station 0 is the starting station, and station 1 and 2 are the passing stations.

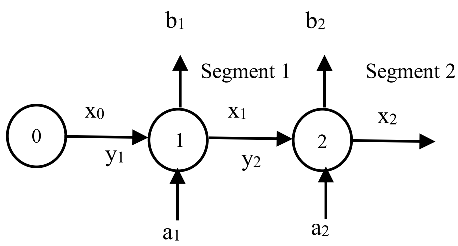

FIGURE 14. Abstract structure of the expressway.

Using the big data of the expressway traffic network in China, the data were obtained on November 1, 2020, and the time correction factors of the two road segments were obtained. Based on the data on November 1, 2021, the number of vehicles on road segment 1 and 2 from t = 0 to t = 23 is predicted. The relationship between the predicted value and the real value is shown in Fig.15 and 16, respectively, and the predicted value is consistent with the real value.

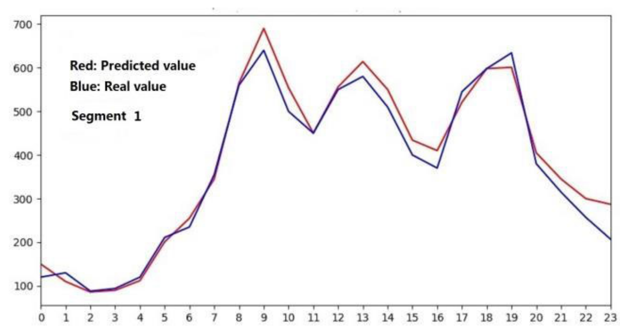

FIGURE 15. The predicted result of the road segment 1.

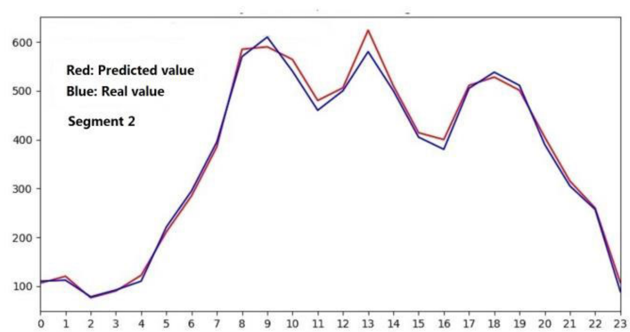

FIGURE 16. The predicted result of the road segment 2.

2) METHOD OF TRAFFIC SITUATION

As shown in Fig.17, based on the Baidu online map API, the color of the first road segment is green; therefore, the average driving speed is 110 km/h, as shown in Table 2.

As shown in Fig.18, there is a part of the road segment that is red in color and congested. The total length from S1 to S2 is 67 km, and the length of the congestion segment is 30 km.

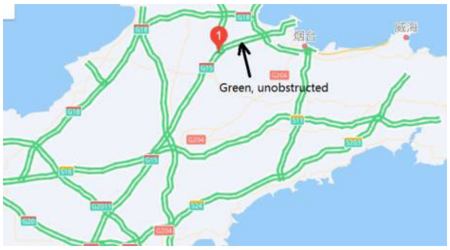

FIGURE 17. Traffic situation of expressway (1).

FIGURE 18. Traffic situation of expressway (2).

According to Table 2:

$$t_1 = \frac{L_1}{V_1} = \frac{67-30}{110} = 0.34\text{h}$$

$$t_2 = \frac{L_2}{V_2} = \frac{30}{50} = 0.6\text{h}$$

Because $t_1 < t_2$, from (14),(15) and (16), we get:

$$t = \frac{L_1}{(V_1 - V_2)} = \frac{37}{110-50} = 0.62\text{h}$$

$$L_1' = V_1 * t = 110 * 0.62 = 68.2\text{km}$$

$$L_2' = L_2 - V_2 * t = 30 - 50 * 0.62 = -1$$

Because $L_2' < 0$, we can ignore the congestion segment, and the average speed is equal to $V_1 = 110$ km/h. This means that the congestion segment disappears gradually when the vehicle runs from station 1 to station 2.

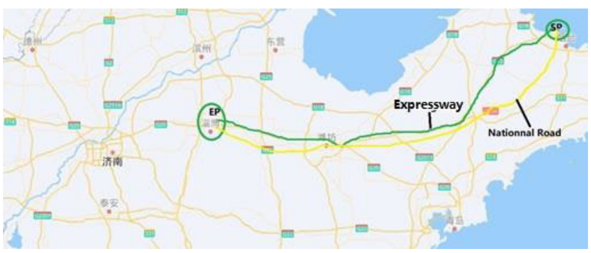

FIGURE 19. Map of the road network.

B. SIMULATION OF DRIVING STRATEGY

As shown in Fig.19, the green line represents the expressway, and the yellow line represents the national highway. The abstract road network structure is illustrated in Fig. 20

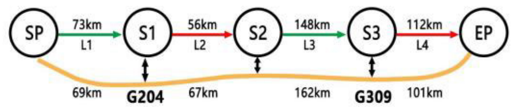

FIGURE 20. Abstract structure of the road network.

From the starting station (SP) to the end station (EP), there are five stations and four road segments, and the distance of each segment is shown in Fig.20. There are two national highways which are G204 highway and G309 highway, and the distance of each segment is shown in the figure (yellow color). Each segment of the national highway is divided into several small road segments that are not drawn here. Every station is linked to a national highway, so it is convenient to switch between expressways and national highways.

Simulation conditions setting: the desired time is 4.5 h. Road condition settings: based on the traffic situation, L1 is green, and the speed is 100 km/h; L2 is congested, and the speed is 40 km/h; L3 is green, and the speed is 105 km/h. There is a traffic accident on the segment L4, and the delay time is 1.5 h.

Step 1: Determine whether the first road segment (L_1) of the expressway is drivable.

Total length: $L = 73+56+148+112=389$ km

Number of road segment: n =4

Average speed: $\vec{v}$ =389/4.5 = 86.5 km/h

From (3), the theoretical driving speed of the first segment:

$$m = n * \vec{V} = 4 * 86.5 = 346 \text{ km/h}$$

$$\begin{aligned}\sum\nolimits_{i=1}^{n} \sqrt{L_i} &= \sqrt{L_1} + \sqrt{L_2} + \sqrt{L_3} + \sqrt{L_4} \\ &= \sqrt{73} + \sqrt{56} + \sqrt{148} + \sqrt{112} \\ &= 8.5 + 7.5 + 12.2 + 10.6 = 38.8 \text{ km}\end{aligned}$$

$$V_{t1} = \frac{m \cdot \sqrt{L_1}}{\sum_{i=1}^{n} \sqrt{L_i}} = \frac{346 * 8.5}{38.8} = 75.8 \text{ km/h}$$

As shown in Fig.20, the color of the first segment is green and the estimated speed (V_{p1}) is 100 km/h. Therefore, $V_{p1} > V_{t1}$, and we can get on the first segment and drive forward.

Step 2: Determine whether the second road segment (L_2) of the expressway is drivable.

When the first segment is completed, the actual average driving speed is 105 km/h, and the time is spent:

$t_1 = \frac{73}{105} = 0.69$h.

The remaining desired time: 4.5 – 0.69 =3.81 h

The average speed of the remaining segments:

316/3.81= 82.9 km/h

From (3), the theoretical driving speed of the second segment:

$$m = n * \vec{V} = 3 * 82.9 = 248.7 \quad \text{km/h}$$

$$\begin{aligned}\sum\nolimits_{i=2}^{n} \sqrt{L_i} &= \sqrt{L_2} + \sqrt{L_3} + \sqrt{L_4} \\ &= \sqrt{56} + \sqrt{148} + \sqrt{112} \\ &= 7.5 + 12.2 + 10.6 = 30.3 \quad \text{km}\end{aligned}$$

$$V_{t2} = \frac{m \cdot \sqrt{L_2}}{\sum_{i=2}^{n} \sqrt{L_i}} = \frac{248.7 * 7.5}{30.3} = 61.6 \quad \text{km/h}$$

Because L_2 is congested and the speed (V_{p1}) is 40 km/h, $V_{p2} < V_{t2}$, so it does not satisfy the driving condition. It is divided into two cases. (1) According to the method in the literature [5], judge whether the national highway is also congested. If it is not, choose to get off the expressway from station 1 and get on the national highway. (2) If the national highway is also congested and the driving time is much longer than the expressway time, continue to drive on the expressway. Although the second segment is congested, there is no choices.

Assuming that the national highway is not congested, the theoretical time of the second segment is

56/61.6 = 0.9 h.

The time is set as the desired time from station 1 to station 2 on the national highway, and the driving route is completed based on the method in the literature [5]. When the route is finished, the average speed is 65 km/h; therefore, the time spent on the route is 0.86 h.

Step 3: Determine whether the third road segment (L_3) of the expressway is drivable.

The remaining desired time: 3.81 – 0.86 =2.95 h

The average speed of the remaining segments:

260/2.95 = 88.1 km/h

From (3), the theoretical driving speed of the third segment:

$$m = n * \vec{V} = 2 * 88.1 = 176.2 \quad \text{km/h}$$

$$\begin{aligned}\sum\nolimits_{i=3}^{n} \sqrt{L_i} &= \sqrt{L_3} + \sqrt{L_4} \\ &= \sqrt{148} + \sqrt{112} \\ &= 12.2 + 10.6 = 22.8 \quad \text{km}\end{aligned}$$

$$V_{t3} = \frac{m \cdot \sqrt{L_3}}{\sum_{i=2}^{n} \sqrt{L_i}} = \frac{176.2 * 12.2}{22.8} = 94.2 \quad \text{km/h}$$

Because L_3 is green and the speed (V_{p3}) is 105 km/h, $V_{p3} > V_{t3}$, and we can get on the third segment again and drive forward.

Step 4: Determine whether the fourth road segment (L_4) of the expressway is drivable.

When the third segment is finished, the average speed is 105km/h; therefore, the time spent on the segment is 1.4 h. The remaining desired time: 2.95 - 1.4=1.55 h. Due to the traffic accident on the last segment of the expressway, the delayed time is 1.5 hours. The sum of the driving time and delayed time exceeds the remaining desired time; therefore, it is necessary to get off the expressway from station 3 and drive on the national highway to destination 4. The remaining desired time is set as the desired time from station 3 to station 4 on the national highway, and the driving route is completed based on the method in the literature [5]. When the route is finished, the average speed is 75 km/h, and the time spent on the route is 1.5h. This economizes the desired time 0.05h, and the driving task is completed successfully.

C. EXPERIENCES AND ANALYSIS

(1) The desired time is set as long as possible within the allowable range, considering factors such as road conditions. According to experiences, the total average speed can be set first, and the desired time can be calculated.

(2) Non-expressway (national highway, provincial highway, etc.) is slow. When a vehicle turns into the expressway segment, it can run with the maximum limit speed to save time and compensate for the time lost on the non-expressway road.

(3) As long as the road segment is drivable, the actual driving speed is generally greater than the estimated driving speed. Thus, the actual driving time is less than the theoretical driving time, which meets the actual demand. Because there are vehicles leaving from the next station ahead with the passing of time, the number of vehicles in front of the road segment will be reduced; thus, the traffic speed will increase appropriately, which is the main feature of the expressway.

(4) For actual driving, there may be no congestion at the beginning; however, congestion appears after driving for a period of time. It is congested at the beginning, but the congestion disappears after driving for a certain period of time. From the perspective of instantaneous speed, this phenomenon exists, but we use the average speed of the road segment; therefore, the influence of instantaneous speed is eliminated. We use the number of vehicles on the road segment to estimate the average speed, which not only overcomes the shortcomings of predicting the future speed with the current speed but also overcomes the shortcomings of other traditional traffic volume prediction models.

From the entrance to the next exiting station, because the boundary of the expressway is close, there are no other vehicles entering the segment (except the expressway intersection), and only the vehicles leave from the next station; therefore, it is scientific and reasonable to adopt the average speed.

(5) In the driving process, if a traffic accident occurs ahead, the period of time should be delayed. When we judge whether the next road segment is drivable, it is necessary to remove the delayed time; otherwise, unreasonable calculation results will be obtained.

VIII. CONCLUSION

Because expressways are currently an important highway traffic route, all of drivers choose expressway route first. At present, the lack of unified traffic flow control often causes expressway congestion and reduces driving efficiency. Therefore, the purpose of driving on an expressway will not be achieved, and sometimes it is not as fast as driving on a non-expressway network. On the other hand, when a traffic accident occurs on the next road segment and results in stopping to drive, the driver does not know whether he switches to other non-expressway networks because of the lack of judgment. Thus, he can only continue to drive to the next segment and wait for the accident to be dealt with. This delays a lot of driving time and increases the travel costs. Therefore, it is very urgent and important to study intelligent driving strategies for expressways.

With the development of expressway network connection technology and big data technology, intelligent driving strategies for expressways have become a reality [31], [32], [33]. The goal of the intelligent driving strategy of expressways is to avoid congested roads or traffic accidents, achieve dynamic switching between expressways and other non-expressway networks, and ensure the desired time from departure to destination. Based on the above objectives, we propose a feasible expressway intelligent driving strategy that has the following advantages. (1) According to the toll station, an expressway is divided into several road segments, and the traffic situation is analyzed based on each road segment; (2) Based on the driving characteristics of the expressway, only the average speed of the road segment is considered, and the relationship between the number of vehicles on the road segment and the average speed is established. It does not need to consider the time and space characteristics of the entire road, and the model is not complex; (3) The model for predicting the number of vehicles only needs the data of entering and leaving vehicles at toll station, which can be easily obtained through the road network big data and is real-time; (4) Based on the existing online map platforms such as Gaode and Baidu, we can obtain the driving speed of the road segment; (5) The desired driving time is set as a controlled target, which can improve the travel efficiency and ensure the desired driving time by calculating the theoretical and estimated driving speed of the road segment, judging the expressway traffic situation, realizing the switching between the expressway and other road networks, and avoiding the traffic accident segment and congested road segment.

These methods provide an important reference for the design and implementation of intelligent transportation systems based on expressway travel. They are simple and easy to be implemented, and are currently being used in the design of intelligent transportation systems. The future research work is to integrate the ETC (Electronic Toll Collection) data, manual toll collection data, video surveillance data of each entrance and exit station of expressways, as well as the whole monitoring data of road segments, expressway network data and other data information. Through data mining and processing, we can accurately obtain the real-time data of vehicle driving on expressways, judge the current road traffic situation on real-time and accurately, and provide important information guarantee for the realization of the intelligent driving strategies in this paper.

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