Research on Rapid Warning Model of Expressway Congestion Abnormal Events Based on ETC Gantry System

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ABSTRACT

Rapid warning of abnormal expressway congestion events is an important means for managers to manage and make decisions, guide them to choose reasonable travel paths, and improve the efficiency of highway traffic. In this paper, by analyzing the data of vehicle passage time, traffic speed and traffic density of the highway ETC gantry system, this paper focuses on the data characteristics of the ETC gantry system, constructs a highway congestion index fusion model based on speed and traffic density, and develops a rapid warning model for abnormal congestion events in order to detect abnormal events of highway congestion in advance, which provides strong support for early identification of the operation status of the road network and early detection of abnormal congestion events. After research, the rapid warning model of highway congestion abnormal events based on ETC gantry system is of great significance to improve the traffic safety level of road sections and reduce the loss of life and property caused by traffic accidents. According to statistics, the overall highway accident rate can be reduced by more than 10%, and the rescue time can be shortened by 15.7%.

Keywords- expressway network; ETC gantry system; congestion abnormal events; rapid warning model

1. INTRODUCTION

In 2019, in accordance with the deployment of the Party Central Committee and the State Council, the project of canceling expressway provincial boundary toll stations was launched, and by the end of the year, 29 provinces (autonomous regions and municipalities directly under the central government) would cancel expressway mainline toll stations and realize online toll collection; The ETC gantry system is set up between the two interconnections and provincial boundaries, and more than 20,000 sets of ETC gantry systems have been built nationwide, building a free-flow toll collection network with the largest number of users, the largest road network and advanced technology in the world.

ETC gantry system adopts advanced DSRC, video, redundancy and other technologies, vehicle data is complete and accurate, stable and reliable, the scale covers all interconnections of the national highway, the gantry, power supply, communication and other hardware resources are good, but it is currently only used for highway toll. How to use ETC gantry system data to carry out intelligent application has become an urgent problem for the Ministry of Transport and the industry. The daily data generated by the highway ETC gantry system is huge, with many types of data, wide coverage, strong real-time, high accuracy, high reliability, convenient data collection, summary, analysis and processing, and rich content of generated results, which provides strong data and hardware support for thoroughly solving the accuracy and timeliness of intelligent applications such as highway network operation monitoring, driving behavior monitoring, toll audit, vehicle credit management, and vehicle-road coordination, and finds a way to greatly improve highway operation management. The feasible and fast way of emergency response and public service level can effectively accelerate the process of intelligent construction[1-2].

This paper focuses on the rapid warning model of congestion abnormal events based on ETC gantry system, and uses the ETC gantry road network number, ETC gantry section number, ETC gantry number, ETC gantry number, license plate number, license plate color, capture time, driving direction, passing time, lane code, pictures and other data generated by the ETC gantry system to develop a rapid warning model for congestion abnormal events, which provides strong support for early identification of road network operation status and early detection of congestion abnormal events. The speed ranges of different congestion degrees from unimpeded to heavy congestion in different speed limit sections of expressways are respectively corresponding to each other[3].

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2. RESEARCH ON DATA FEATURE MINING OF ETC GANTRY SYSTEM

2.1 ETC gantry system data type

The ETC gantry system can automatically identify the front and rear license plate color and license plate number of all passing vehicles (including ETC vehicles and MTC vehicles), and after automatic identification by the system, it can be manually checked and corrected, and all the recognized license plate color, license plate number and time, gantry information and vehicle image information are formed into image flow records. The data types can be mainly divided into: ETC transaction flow (or pass), ETC pass record, image flow record, CPC card pass record. This is shown in Figure 1:

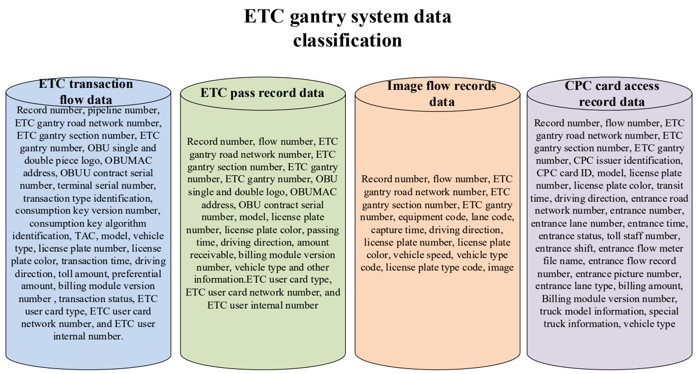

Figure 1. ETC gantry system data classification

ETC traffic record data includes record number, flow number, ETC gantry road network number, ETC gantry section number, ETC gantry number, ETC gantry number, OBU single and double piece logo, OBU MAC address, OBU contract serial number, model, license plate number, license plate color, passing time, driving direction, receivable amount, billing module version number, vehicle type and other information. If it is a dual-chip OBU, it also includes the ETC user card number, ETC user card type, ETC user card network number, ETC user card internal number, etc.

The image flow record data includes record number, flow number, ETC gantry road network number, ETC gantry section number, ETC gantry number, equipment code, lane code, capture time, driving direction, license plate number, license plate color, vehicle speed, vehicle type code, license plate type code, image and other information.

CPC card traffic record data includes record number, flow number, ETC gantry road network number, ETC gantry section number, ETC gantry number, CPC MAC address, CPC issuer identification, CPC card ID, model type, license plate number, license plate color, passing time, driving direction, entrance road network number, entrance number, entrance lane number, entrance time, entrance status, toll staff number, entrance shift, entrance meter file name, entrance flow record number, entrance picture number, entrance lane type , billing amount, billing module version number, truck model information, special truck information, vehicle type and other information. For the provincial boundary ETC gantry system, the CPC card traffic record data should also add all the transit information of the province (region, city) read from the CPC card on the above basis.

2.2 ETC gantry system data feature mining

The data generated by the ETC gantry system is comprehensive and diverse, and through the mining of massive data, the intrinsic correlation and change trend of various data can be found out[4]. After sorting out and integrating these characteristics, more intelligent applications serving expressways can be extended, thereby improving the management capabilities and service levels of expressways, and accelerating the construction of intelligent applications of expressways.

In order to improve the efficiency of highway traffic, timely detect and deal with emergencies, and better provide services for public travelers, it is necessary to collect information such as highway road vehicle traffic and equipment operation status in a timely manner, so as to realize the monitoring of the operation of the entire highway network by highway managers[5-6]. Through the mining and analysis of the data generated by the ETC gantry system, such as ETC traffic records, image flow records, CPC card traffic records, ETC gantry numbers, lane codes, capture time, driving direction, license plate numbers, license plate colors, vehicle speed, vehicle type codes, license plate type codes, images and other information, the operation monitoring of the road network can be realized, such as operation status judgment, traffic volume prediction, travel time prediction and other functions.

3. ESTABLISHMENT OF RAPID WARNING MODEL FOR CONGESTION ABNORMAL EVENTS

3.1 ETC gantry system data type analysis

x1: Counts the number of passes in the last N minutes of starting Station A;

x2: Calculate the number of passes in the last N minutes of the target Station B;

x3: The number of vehicles passing AB at the same time x3.

As shown in Equation 1,Calculate the coefficient of variation for three results x1, x2, x3:

$$\mathrm{cv} = 1/(1 + e^{-\frac{std(x1',x2',1.5*x3')}{mean(x1',x2',1.5*x3')}}) \quad (1)$$

3.2 Model calculation logic flow

Step1:

As shown in Equation 2,Calculate the last N minutes for the road section between two ETC gantry systems adjacent to AB:

$$\mathrm{N} = \frac{S_{AB}}{v_{lowest}} * \alpha * 60 \quad (2)$$

S_{AB} is the distance between the AB ETC gantry system, and v-lowest. is the minimum speed of the road section, usually 60km/h, α is a multiple of the minimum driving speed passing time, the default α=2, the same can be obtained BA driving situation. If all road segments take the same value, this step is omitted; If it is different, offline calculation is good, and the configuration table is used for real-time calculation to load.

Step2.1:

Calculate the number of vehicles passing in the past N minutes x1 of the starting Station A, calculate the number of passing cars in the past N minutes of the target Station B x2, and at the same time pass the number of vehicles x3 through AB, subject to the influence of equipment factors, in order to statistically calculate the accuracy of the index, consider the three-degree topology relationship through the driving trajectory route, and modify the calculation results of x1, x2, x3. This is shown in Figure 2:

Figure 2. Schematic diagram of the start and end points of the road section

Calculate the intersection of the three ETC gantry system vehicle sets before passing through the starting point A (exclusive) and the three ETC gantry system vehicle sets after passing through the target B point (inclusive), and the result is then merged with the set of vehicles passing through A, the result is A^', expressed by the formula as follows:

$$A' = Set(A) \cup \{[Set(A-3) \cup Set(A-2) \cup Set(A-1)] \cap [Set(B-3) \cup Set(B-2) \cup Set(B-1) \cup Set(B)]\} \quad (3)$$

Calculate the intersection of the three ETC gantry system vehicle sets before passing through starting A (inclusive) and the three ETC gantry system vehicle sets after passing through target B point (excluded), and the result is merged with the vehicle set passing through B, the result is $\boldsymbol{B'}$, expressed by the formula as follows:

$$B' = \mathrm{Set(B)} \cup \{[\mathrm{Set(A-3)} \cup \mathrm{Set(A-2)} \cup \mathrm{Set(A-1)} \cup \mathrm{Set(A)}] \cap [\mathrm{Set(B-3)} \cup \mathrm{Set(B-2)} \cup \mathrm{Set(B-1)}]\} \quad (4)$$

According to the above results, the number of cars passing through station A($x1'$), the number of cars passing through station B($x2'$)., and the station passing through AB at the same time($x3'$). expressed by the formula as follows:

$$x1' = \mathrm{NUM(Set(A'))} \quad (5)$$

$$x2' = \mathrm{NUM(Set(B'))} \quad (6)$$

$$x3' = \mathrm{NUM}(\mathrm{Set}(A') \cap \mathrm{Set}(B')) \tag{7}$$

Step2.2:

If the starting point is the ETC gantry system (Which can be judged by the siteNo length less than 10), the mast calculation result with the siteNo length greater than 10 is found forward instead of the x1 value, and the original small road section number A_B unchanged; Similarly, if the end point is the same, find the mast with a length greater than 10 and replace the x3 value by finding siteNo backwards.

Step3:

As shown in Equation 8,Calculate the coefficient of variation for three results x1, x2, x3:

$$\mathrm{cv} = 1/(1 + e^{-\frac{std(x1',x2',1.5*x3')}{mean(x1',x2',1.5*x3')}}) \tag{8}$$

If the denominator is 0,x1=x2=x3=0, then cv = 1.

Step4:

Determine the type of abnormal event based on different indicators:

Set the initial state to status = 0(smooth);

Assuming x1>0, x2=0, x3=0 and the previous state is not equal to 1 (congestion), then status = 2 (starting device abnormal) x1=0, x2>0, x3=0 and the previous state is not equal to 1 (congestion), then status = 3 (target device abnormal);

Condition 1: CV = 1 and the previous state is equal to 1 (congestion), and the congestion index calculation result of 5 minutes before and after the non-first calculation and the same road section is greater than 7;

Condition 2: 0.65<=CV<1, and the non-first calculation and the calculation result of the congestion index in the 5 minutes before and after the same road section is greater than 7;

If any of the above conditions are met, status=1 (congestion), otherwise: status=0 (Smooth).

Step5:

The duration of the same state abnormal event is accumulated;

Set the initialization time time=1 // 1 minute to calculate the congestion judgment result.

Step6:

The first congestion event indicator (that is the congestion event forecast flag) is used to determine whether the large-screen display initializes the alarm variable if_show=0 // Only the first congestion requires alarm display.

Step7:

Results are stored and updated.

When if_show=1 data needs to be output, it is written to the database.

Write out the data content:

Event number: TRN+time, for example:TRN20191001101001

Event date: 20191001

Event time: 00:10

Section name: A_B, for example: 20601_20603

Event type: status, for example: 2

Impact duration: time, e.g. 20 (unit: minutes)

Step8:

Table 1. Associate additional output information

Event Num	Event Date	Event Time	The name of the minimum segment	Event Type	Duration of the impact	Direction	Event hub point station	Road Name
TRN20191001101000	20191001	10:10	20601_20603	0	1min	1	K10+500	G60

As shown in Table 1,When if_show=1, the data is written to the database as an insert operation. The event numbering system generates unique IDs.

When if_show=0 and status=1, the data is updated and the section name, event number, event date, and time are unchanged, affecting the duration of the update.

Description: Directions, event center point stations, and road names are associated through static attribute tables between adjacent sites.

4. EXAMPLE ANALYSIS

4.1 Segment selection and system deployment

The Shanghai-Hangzhou-Ningbo Expressway is the first expressway to be built in Zhejiang, passing through four cities of Jiaxing, Hangzhou, Shaoxing and Ningbo, with a total length of 248 kilometers. As the owner and manager of the entire road section, Shanghai-Hangzhou-Ningbo Expressway Company needs to have a comprehensive understanding of the traffic situation of each station and section of the road section, and at the same time can also release the congestion index to the public, optimize the public's choice of roads, and play a good role in strengthening traffic control by the management department. Compared with some Internet map companies, highway companies have more comprehensive, accurate and real-time road traffic data, and have the conditions to calculate a more accurate congestion index[7]. The Shanghai-Hangzhou-Ningbo Expressway operation monitoring platform integrates the data of 490 ETC gantries in Shanghai-Hangzhou-Ningbo, equipment data such as field bayonets, vehicle detectors, toll stations and all toll lanes, and is the intersection node of the basic communication network of Shanghai-Hangzhou-Ningbo Expressway, as well as the management center, collection center, processing center, storage center and exchange center of various data resources.

As of May 28, 2020, the Shanghai-Hangzhou-Ningbo Expressway operation monitoring platform has a total of 14.2 billion pieces of data and a total of 41,960 GB of unstructured data, including 77 million pieces of ETC gantry system data, 73 million pieces of traffic police bayonet data, 33 million pieces of main line bayonet data, 9.8 million pieces of gantry transaction data, and 5.2 million pieces of video structured data.

4.2 Model validation

(1) Case 1

G60 section (G0060091000_G0060094050) 2 RSU equipment sections (station K91+000 to K94+050), playback through the video surveillance platform (camera station K91+800) Shanghai direction monitoring:

2023-03-01 16:29:10Truck accident throwing objects occupy 2 lanes;

2023-03-01 16:31:00 Traffic police arrived at the scene, the section began to be congested;

2023-03-01 16:32:00~2023-03-01 16:40:00 Congestion intensified and began to slow down.

Corresponding to the minimum cross-section G0060091000_G0060094050 2023-03-01 16:29:00~16:35:00 The change trend of traffic situation indicators is shown in Figure 3:

G60	G0060091000_G...	K91+000	K94+050	104.59	0.65	2023-03-01 16:2...
G60	G0060091000_G...	K91+000	K94+050	90.5	1.56	2023-03-01 16:3...
G60	G0060091000_G...	K91+000	K94+050	83.82	2.23	2023-03-01 16:3...
G60	G0060091000_G...	K91+000	K94+050	76.97	3.04	2023-03-01 16:3...
G60	G0060091000_G...	K91+000	K94+050	72.99	3.5	2023-03-01 16:34:00
G60	G0060091000_G...	K91+000	K94+050	65.7	4.18	2023-03-01 16:3...
G60	G0060091000_G...	K91+000	K94+050	58.94	4.69	2023-03-01 16:3...

Figure 3. Case 1 Traffic situation indicator change trend chart

From 16:30 to 16:35, the congestion index rose sharply from 1.5 to 4.69, and the average speed of the road section dropped from 104 to 58. At 16:35, the congestion level is moderate or above, and the delay between entering the congestion state and the video of the surveillance platform is 1 minute.

(2) Case 2

G60 section (2604_G006033001001120010) Shenshi hub (pile K143+500 to K141+600), playback through the video surveillance platform (camera station K143+150) Hangzhou direction monitoring:

2023-03-01 20:08:00Vehicle rollover occurred in the direction of Shanghai, and vehicles behind began to slow down congestion. Corresponding to the minimum cross-section 2604_G006033001001120010 2023-03-01 20:06:00~20:11:00 The change trend of traffic situation indicators is shown in Figure 4:

road_block	min_section	s_trace_name	e_trace_name	avg_speed	block_index	calc_time
G60	2604_G00603300...	沈士枢纽	K141+600	84.56	1.1	2023-03-01 20:0...
G60	2604_G00603300...	沈士枢纽	K141+600	76.12	1.93	2023-03-01 20:0...
G60	2604_G00603300...	沈士枢纽	K141+600	76.16	1.95	2023-03-01 20:0...
G60	2604_G00603300...	沈士枢纽	K141+600	65.63	2.91	2023-03-01 20:10:00
G60	2604_G00603300...	沈士枢纽	K141+600	53.35	4.35	2023-03-01 20:1...
G60	2604_G00603300...	沈士枢纽	K141+600	56.64	4.03	2023-03-01 20:1...

Figure 4. Case 2 Traffic situation indicator change trend chart

(3) Case 3

G92 section (1043_G009233001001510020) Yuyao Fu Station (pile K271+500 to K273+900), playback through video surveillance platform (camera station K272+500) Hangzhou direction monitoring:

11:26 Congestion began in the direction of Yuyao Interconnection Ningbo;

11:26:40~11:30:00 Large traffic queue congestion intensifies. Corresponding to the minimum cross-section 1043_G009233001001510020 2023-03-24 11:25:00~11:30:00 The change trend of traffic situation indicators, as shown in Figure 5:

road_block	min_section	s_trace_name	e_trace_name	avg_speed	block_index	calc_time
G92	1043_G00923300...	余姚付站	K273+320	76.04	2.56	2023-03-24 11:2...
G92	1043_G00923300...	余姚付站	K273+320	43.87	6.01	2023-03-24 11:2...
G92	1043_G00923300...	余姚付站	K273+320	34.44	6.97	2023-03-24 11:28:00
G92	1043_G00923300...	余姚付站	K273+320	29.48	7.7	2023-03-24 11:2...
G92	1043_G00923300...	余姚付站	K273+320	27.35	8.04	2023-03-24 11:2...
G92	1043_G00923300...	余姚付站	K273+320	32.74	7.18	2023-03-24 11:3...

Figure 5. Case 3 Traffic situation indicator change trend chart

From 11:25 to 11:28, the congestion index immediately rose from 2.5 to 7.7; at 11:29, the congestion index rose to 8, which is basically complete congestion. Compared with video, the time is consistent and there is basically no delay.

Figure 6. Cross-section congestion indicator trend graph

From the trend of the cross-sectional situation indicator on the day, from 11:25 to 11:35, there was an instantaneous congestion peak. This is shown in Figure 6.

4.3 Validation results and analysis

The realization of the rapid warning model of congestion abnormal events based on ETC gantry system mainly relies on the ETC gantry road network number, ETC gantry section number, ETC gantry number, license plate number, license plate color, capture time, driving direction, passing time, lane code, pictures and other data generated by the ETC gantry system.

The verification of algorithm results is carried out by combining video data and third-party navigation data, and continuous sampling from congestion points and non-congestion points is verified[8-9]. Referring to the table below, the congestion index corresponds to the color shown. As shown in Table 2,

Table 2. Highway congestion index

Congestion Index	Road Status	Illustration Color	Corresponds to Road Conditions	Travel time
0-2	Smooth	Green	There is basically no road congestion	Drive according to the road speed limit standard
2-4	Basically unblocked	Light green	There is a small amount of road congestion	It takes 0.2 to 0.5 times longer than when it is unblocked
4-6	Mild congestion	Light yellow	Some stations are congested	It takes 0.5 to 1.2 times longer than when it is unblocked
6-8	Moderate congestion	Yellow	Major station congestion	It takes 1.2 to 2.5 times longer than when it is unblocked
8-10	Severe congestion	Red	Most sections of the road section are congested	It takes more than 2.5 times more time than when it is unblocked

When the road is congested, the real-time large screen corresponding to the road section is marked in red, as shown in the figure below, and the live video results in the figure show that the traffic density is large at this time, and the traffic flow is in a slow state. This is shown in Figure 7:

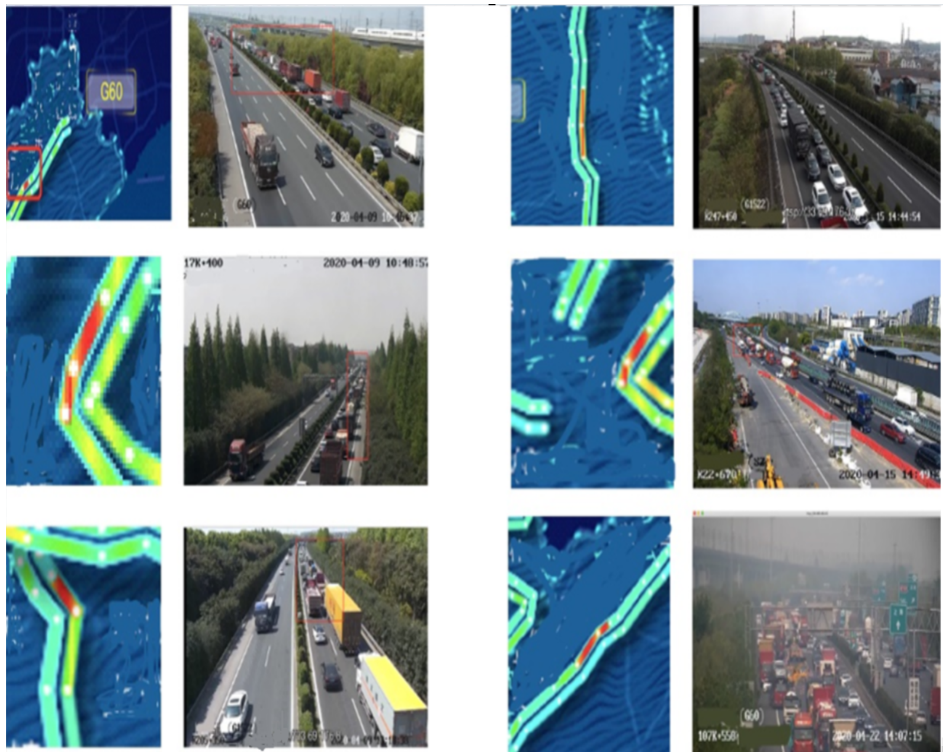

Figure 7. Congestion index test of congested road sections

Key road sections and nodes such as hubs and interconnections need more accurate data, and through the test results, if you need to obtain more accurate results, you need to increase the equipment deployment density for key road sections and nodes such as hubs and interconnections, and it is recommended that RSU devices be encrypted according to 2-3 kilometers.

5. CONCLUSIONS

Rapid warning of abnormal highway congestion events is an important means for managers to manage and make decisions, guide them to choose reasonable travel paths, and improve the efficiency of highway traffic[10-11]. In this paper, by analyzing the data of vehicle passage time, traffic speed and traffic density of the highway ETC gantry system, this paper focuses on the data characteristics of the ETC gantry system, constructs a highway congestion index fusion model based on speed and traffic density, and develops a rapid warning model for abnormal congestion events in order to detect abnormal events of highway congestion in advance, which provides strong support for early identification of the operation status of the road network and early detection of abnormal congestion events. After research, the rapid warning model of highway congestion abnormal events based on ETC gantry system is of great significance to improve the traffic safety level of road sections and reduce the loss of life and property caused by traffic accidents. According to statistics, the overall highway accident rate can be reduced by more than 10%, and the rescue time can be shortened by 15.7%.

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