

An Optimal Traffic Detector Method Based on Travel Time Estimation Model

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Abstract: For finding the optimal distribution distance of traffic detectors, a linear traffic flow model and an incident wave propagation model are generated first by analyzing the influencing factors of traffic accident on rapid urban expressway. Then the impact of travel time on the accuracy of traffic incident detection algorithm is estimated by error based on an improved travel time prediction model. An optimal detector distribution distance can be determined when allowable time estimation accuracy is achieved. TransModeler software is then adopted for traffic incident simulation. Experimental results show the presented detector distribution method can detect traffic accidents on the section quickly and effectively. Copyright © 2013 IFSA.

Keywords: Urban expressway, Travel time, Linear traffic flow model, TransModeler simulation, Optimal detector distribution method.

1. Introduction

Urban highway is a high-speed road with one-way multi-lane ensuring large and continuous traffic capacity located in central city. Once a traffic incident happens and if not promptly treated, there will be congestion in the urban highway.

For quick and accurate detection of traffic incident, automatic traffic incident detection method is implemented based on the real-time traffic information collected by vehicle detectors. Through the analysis on the upstream and downstream traffic condition of accident position, the purpose of event detection can be achieved.

Indirect incident detection method can be divided into two parts: optimal traffic detector distribution method and automatic incident detection algorithm. The optimization of traffic detector distribution

method is focused in this paper.

The detector distribution distance has direct impact on the quality of traffic information and the reliability of incident detection. Large detector spacing can reduce the false alarm rate and increases delay of traffic incident detection but without time assurance. Small detector spacing can reduce abnormal incident detection time but the increase false positive rate with an increased system cost.

In existing applications and research, there are no a unified basis standard for reasonable traffic detector distribution spacing yet. The real spacing is set usually such as the use of the 125 m, 200 m, 250 m, 300 m, 500 m 800 m, 1000 m and different values by experience.

Current study on traffic detector distribution mainly include the following methods: detector distribution principles based on the travel time prediction, detector distribution methods based on

traffic status information. The relationship of detector distribution density and travel time estimation error function are calculated [1] to determine the appropriate distance between the fast road detectors by Vissim simulation software. But the interval evaluation speed of the middle road has effect on the accuracy estimation. Function between different detector distribution distances and travel time estimation error has been found [2] by using macro traffic flow model. This method is applicable to road traffic change condition, but its availability to free flow or congested condition remains to be investigated. The impact of event detection algorithm and detector distribution distance is focused and come out to a conclusion that the greater the traffic flow before the incident [3], the more serious the incident, the greater the road traffic capacity declines, the smaller the detector distribution should be. But when the traffic flow is small, specialized traffic incident detection based detector distribution principles needs to be developed.

While in actual application the distribution distance is always different according to different situations. Overall there is an urgent need of more systematic demonstration on the traffic detector distribution.

In this paper, a traffic incident expansion model is first introduced based on roads running conditions and linear traffic flow model. An optimal traffic detector distribution method is proposed here for the purpose of traffic incident detection. The improved detector distribution based on the traffic wave theory-based is proposed to determine the maximum detector distance. The error between predictive travel time based on our incident expansion wave model and the real-time statistical travel time is measured. Transmodeller software is applied for simulation.

Experimental results show that the proposed method is feasible and reliable in actual application, which can meet the accuracy demand and has the largest distribution distance.

2. Traffic Detector Distributions

Traffic incident detection method aims at event detection by analyzing changes of traffic flow up and down the incident location. Real-time traffic information is collected by vehicle detectors. An improved traffic wave model is introduced here. Then effects of travel time on algorithm accuracy based on this model are analyzed to determine the optimal detector distribution distance.

2.1. Linear Incident Wave Expansion Model

When a traffic incident happens at some position of road, the traffic status is shown in Fig. 1, P_1 is the traffic incident shock wave moving upstream, and P_2 is the expansion wave passed downstream. When the

road is completely congested, Q_1 , V_1 is 0, K_1 is congestion density K_j , Q_2 , K_2 is 0, V_2 is free travel speed V_f .

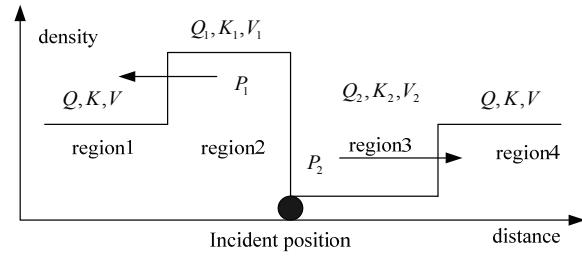


Fig. 1. Traffic wave model under incident condition.

The speed of the incident shock wave and expansion wave is given in equation (1) and equation (2). Then the speed of expansion wave is the speed of normal traffic flow:

$$W_{p1} = \frac{-Q}{K_j - K} \quad (1)$$

$$W_{p2} = \frac{Q}{K} = V \quad (2)$$

Therefore, velocity of traffic incident shock wave can be expressed as:

$$W_{p1} = -V_f \frac{K}{K_j} = -(V_f - V) \quad (3)$$

From the equations above, shock wave velocity under congestion is the difference between the free flow speed and the shock wave velocity before congestion.

2.2. Double- Section Space Model

Consider the road detector distribution condition and algorithm speed, the two-section method is used in this paper for traffic incident detection. The dual-section incident detection algorithm requires that the two waves (shock wave and expansion wave) should respectively arrive on the upstream and downstream detector location in the desired time T_d .

Critical situation is traffic accident point is located near the detection point (X tends to 0 or total road distance L), which requires the slower wave must finish the whole road length of L in limited T_d time and the value of L should satisfy:

$$L_{\max} = \min\left[\left(\frac{\sqrt{\lambda}-1}{2}\right)V_f + V\right]T_d, \quad \left(\frac{\sqrt{\lambda}+1}{2}\right)V_f - V\right]T_d \quad (4)$$

When there is traffic congestion, L should satisfy:

$$L_{\max} = \min[VT_d, (V_f - V)T_d] \quad (5)$$

$$L \leq \min[VT_d, (V_f - V)T_d] \quad (11)$$

2.3. Detector Distribution Model and Optimization Solution

The performance of AID algorithm is affected by many factors. Non-algorithmic factors have impact on signal propagation time and the signal strength arrived. Relationship between the incident signal strength and detector distance is difficult for calibration, while signal propagation time and incident detection time can realize the quantitative calculation.

Detector distance is also artificial factor in all the influencing factors of incident detection algorithms. Therefore, a reasonable detector distribution model is essential for actual application.

When a traffic incident occurs, there will be a blocking or congestion on the road with a road declining flow capacity according to the linear traffic flow model. The capacity reduction factor λ and the congestion degree β are defined as follows:

$$\lambda = \frac{(C - C_L)}{C} \quad (6)$$

$$\beta = \frac{K}{K_j} \quad (7)$$

where C is the road capacity, C_L indicates the remaining capacity of accident point. λ indicates the congestion degree or severity of incident. β is the traffic flow status, which can be calculated by the ratio of traffic flow density before incident and jamming density.

Substituting (6) and (7) into the traffic flow velocity model of equation (1) and (2), it can be get:

$$W_{p1} = \frac{V_f \left(\frac{1-\lambda}{4} - \beta + \beta^2 \right)}{\frac{1}{2}(1+\sqrt{\lambda}) - \beta} \quad (8)$$

$$W_{p2} = \frac{V_f \left(K - \frac{K^2}{K_j} \right) - \frac{(1-\lambda)V_f K_j}{4}}{K - \frac{1}{2}(1-\sqrt{\lambda}) K_j} \quad (9)$$

Then the detector distribution comprehensive model can be introduced as follows:

$$L \leq \min \left[\left(\frac{\sqrt{\lambda}-1}{2} \right) V_f + V T_d, \left(\frac{\sqrt{\lambda}+1}{2} \right) V_f - V T_d \right] \quad (10)$$

When there is traffic congestion, L will be:

Relationship between the incident detector distance L , the severity of incident, the traffic state V before incident and the expected time propagation of incident wave T_d is expressed in (11).

3. Experimental Results

The South Second Ring Road K50 ~ K51 +900 in Xi'an city Shaanxi Province is taken for experiment. The South Second Ring Road is a two-way four-lane urban expressway with length of 34.04 km. The designed free flow speed is 60-80 km/h.

3.1. Traffic Parameters Settings

Actual traffic survey is implemented to get the real-time traffic parameters. The actual road traffic parameter settings are given as follows.

Table 1. Traffic composition of South Second Ring Road.

Vehicle type	Bus	Passenger car	Mini truck
Proportion (%)	8.60 %	74.29 %	17.11 %

Table 2. Traffic parameters of South Second Ring Road.

Traffic parameter	Free flow	Heavy traffic	Congestion
Travel velocity (km/h)	60.5	44.0	30.20

Table 3. Traveling time of Xi'an Second Ring Road.

Vehicle type	Passenger car	Mini truck	Bus
Travel time (s)	17.96	20.36	25.63

3.2. Simulation Settings

The proposed method is run on the Transmodeler software platform for traffic flow simulation. Road condition is set as uniform vehicle distribution model in each direction of road. Simulation time continues for 3600 s at interval of 60 s. Free flow speed is 65 km/h. The incident position is set between the 120 # and 121 # detector.

3.3. Simulation Results

Four types of distribution distance schemes are adopted as 50 m, 100 m, 150 m and 200 m in experiment for simulation. Traffic data of 2 minute

way of accident location from by interval of 1 minute is used in TransModeler platform. Travel time is estimated by the proposed method. Different distribution distance schemes are simulated. When one detector distribution scheme meets the requirements of accuracy larger than 95 % and a maximum distance, it turns out to be the optimal solution.

From upstream direction of accident location, 125 # and 126 # sensor in right side of the first lane are selected with a nearest distance of 33 m from the incident location. The 119 # and 120 # sensor with a distance of 66 m from incident location are also selected. The average velocity and occupancy per minute are shown. It can be seen that from 8:21 average velocity and occupancy both have dramatic changes, which continues until 8:30. It means an obvious influence on traffic flow.

According to Fig. 2 to Fig. 9, average velocity and occupancy collected by the sensor 36 m downstream from the accident location has obvious changes. While average velocity and occupancy collected by the sensor 66m downstream from the accident location has changes little. After the traffic accident, traffic parameters collected by the detectors in the 60 s in the downstream direction.

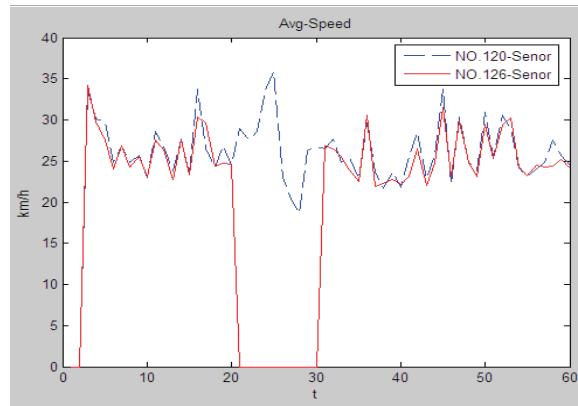


Fig. 2. Average velocity of 126 # and 120 # detector.

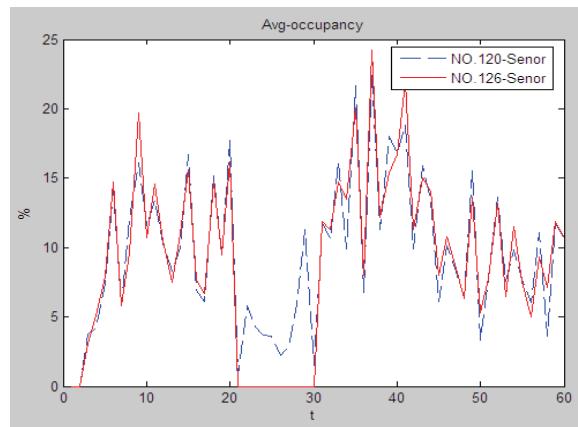


Fig. 3. Average occupancy of 126 # and 120 # detector.

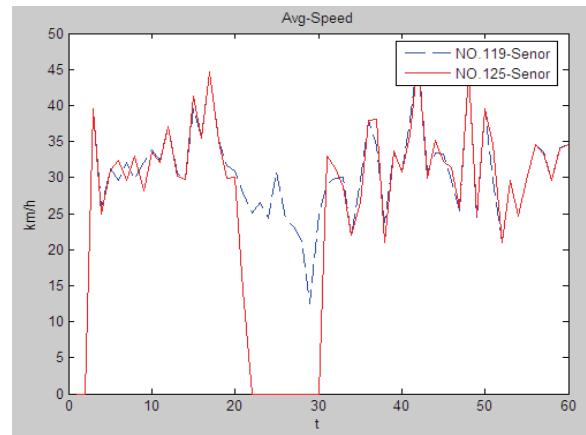


Fig. 4. Average velocity of 119 # and 125 # detector.

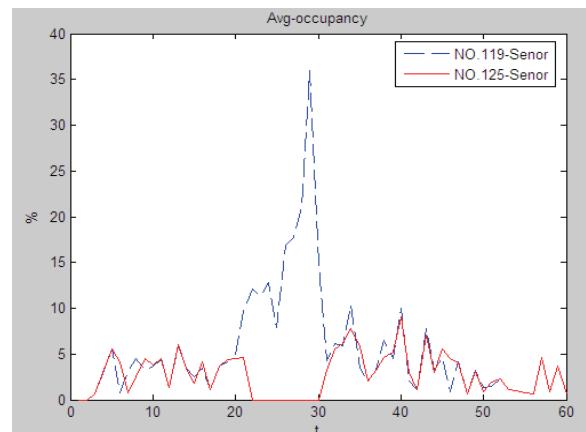


Fig. 5. Average occupancy of 119 # and 125 # detector.

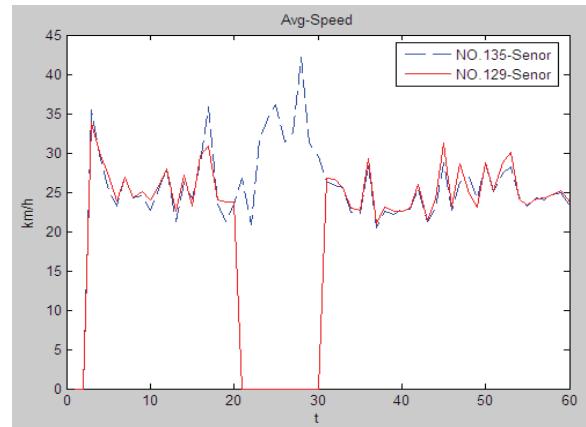


Fig. 6. Average velocity of 129 # and 135 # detector.

From downstream direction of accident location, 127 # and 129 # sensor are selected with a nearest distance of 33 m. The 133 # and 135 # sensor with a distance of 66m are also selected. The average velocity and occupancy per minute are shown.

Travel time estimation error for the four distance schemes are shown in Table 4.

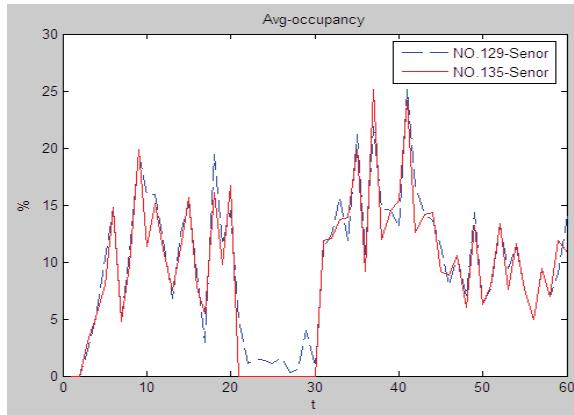


Fig. 7. Average occupancy of 129 # and 135 # detector.

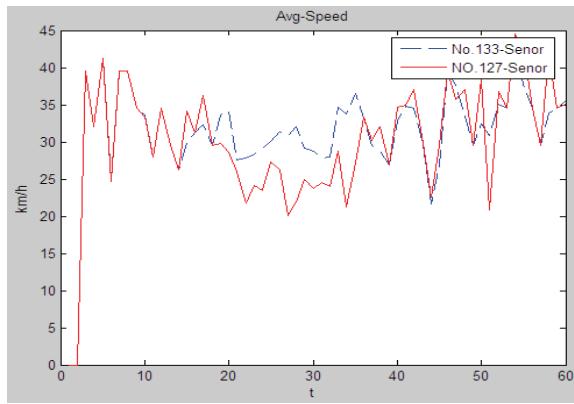


Fig. 8. Average velocity of 127 # and 133 # detector.

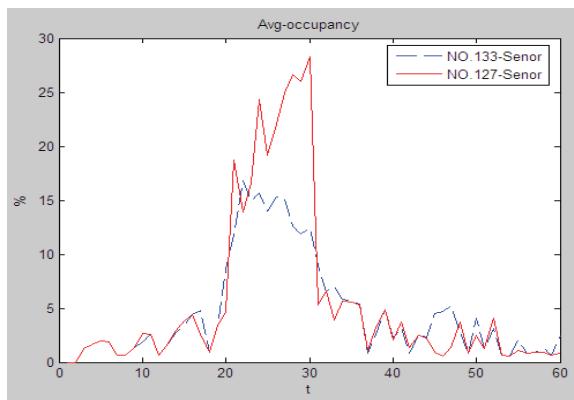


Fig. 9. Average occupancy of 127 # and 133 # detector.

Table 4. Travel time estimation error.

Distance (m)	50 m			100 m		
	1st	2nd	3rd	1st	2nd	3rd
Simulation	1.09	0.83	0.96	1.27	0.87	0.99
Distance (m)	150 m			200 m		
	1st	2nd	3rd	1st	2nd	3rd
Simulation	5.09	4.83	4.96	5.59	6.22	5.81
Error (%)						

From Table 4, the first two distance scheme can meet the accuracy requirements of 5 %. Time accuracy of the third and the forth distribution scheme has larger error. In the third detector spacing scheme, the estimation error is below 5 %. Therefore the optimal detector distance Xi'an Second Ring urban expressway can be determined as 100 m.

This detector distribution distance can ensure abnormality detection from an arbitrary accident position between detectors in 60 s.

4. Conclusions

An optimal traffic detector distribution method based on travel time estimation is presented in this paper. Traffic parameters such as average velocity and occupancy collected by detectors are analyzed to evaluate the impact of traffic accident on detectors both upstream and downstream from the incident location. Travel time between different detector distribution distances is predicted. The error between the predictive traffic value and actual traffic value is analyzed to determine a distribution distance that can both satisfy the accuracy and travel time requirement.

Experimental results show that the optimal detector distribution method proposed in this paper can realize rapid and fast incident detection.

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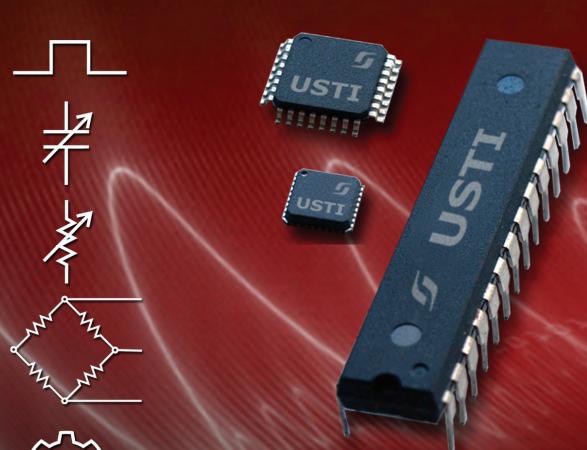
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