A Capacity Assessment Method on Urban Expressway after Traffic Incident

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Abstract

To explore the urban expressway's capacity after a traffic incident, a capacity assessment approach based on VISSIM has been proposed, in which we disassemble the evolutionary processes of local traffic state after traffic incident and analyzed influence factors. Firstly, the ID algorithm of the decision tree was introduced, and accident delay time was solved by using information gain value. Then, according to the Traffic Flow Wave Theory, we determine the congestion dissipation time. Secondly, taking accident delay time as observation period, the maximum vehicle volume through the accident roads was considered as its capacity. Finally, it was simulated and calculated by VISSIM. The results show that, the accident delay time of vehicle anchor and the crowded dissipation time are the minimum, but the residual capacity of the accident roads was the maximum, the portion was 69.926%; the accident delay time of vehicle collision and the crowded dissipation time were the maximum, but the residual capacity of the accident roads was the minimum, the proportion was 49.963%; the residual capacity proportion of the vehicle roll-over, fire and rear-end were 56.87%, 61.611%, 59.796% respectively.

Keywords: urban expressway; decision tree algorithm; accident delay time; crowded dissipate time; VISSIM;

1. Introduction

The sudden accident on urban road is an emergency traffic incident which has a significant impact on the normal operation of urban road and has adverse consequences for life property and social life. The road capacity dropped significantly and the traffic flow was disordered after the occurrence of sudden traffic accident. The sudden traffic accident may also cause traffic congestion of upstream road easily, even cause a number of casualties and property losses, and traffic delays and travel time also increased. It will have a great impact on the regional road network.

For urban road capacity after traffic accident, domestic research mainly is the traffic state identification and impact assessment. For example, Peng Chun-lu studied traffic state prediction and the analysis on the urban rapid road under the abnormal events[2]. Jia Shun-ping establishes an impact assessment system of traffic accident on urban expressways based on microscopic simulation[3]. The foreign research mainly is running state of traffic flow under traffic accident. Persaud B N studied traffic flow operation when an accident happened on the freeway[7].

Through the simulation and research for the urban expressway capacity, this paper provides a theoretical basis for traffic control measures, travel information service, traffic organization and emergency rescue under sudden accident. Effectively protect safe, effective and orderly operation for the city roads.

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2. The local state evolution processes of urban expressway under traffic accidents

After the occurrence of the accident, the road capacity of the accident point will reduce. When the capacity is less than the upstream traffic low, the upstream vehicles will line up in the event point, and continue to extend to the upstream, even extending to the upstream intersection. When the accident is cleared, the road capacity gradually restored, congested traffic low began to dissipate. Continued congestion time is composed of the accident delay time and accident dissipation time, as shown in Figure 1.

The evolution processes of local state are corresponding to continued congestion time is divided into three stages: event monitoring and response, accident treatment, congestion effects continued. The traffic state evolution processes are shown in Figure 2 after an unexpected traffic accident.
According to the figure, analyze the capacity of different accident stage. In order to simplify the analysis, $C_2$ is equivalent to $C_1$.

The first stage: when an unexpected traffic accident causes the temporary closure of the local lanes, the accident lane capacity plunged to zero, it will recover until the unexpected traffic events are cleared. Meanwhile, the vehicles on the accident lane change lane to the adjacent lane, and the traffic flow in a certain range is in a turbulent state. The interaction of the vehicles is relatively large, passable lane capacity is smaller than its normal capacity.

The third stage: the traditional traffic flow theory model (V-K linear model) tries to use the simple formula to reflect the relationship between traffic flow index, regardless of the differences of road capacity in congested and non-congested state. However, many scholars have much in-depth study and discussion about the differences, shows that the average capacity of the congested state ($C_3$) is less than non-congested state ($C_0$).

3. The analysis of influencing factors of city road capacity under traffic accidents

The evolution of the urban road capacity can be seen from the evolution processes of the traffic state after the unexpected traffic events, what are the factors leading to the evolution of this capacity? Different from the urban roads under normal circumstances (taking into account influencing factors of the capacity under normal conditions), the influencing factors of the urban road capacity under traffic accidents has its particularity. In general, it is related with the number of closed lanes near the accident point, the length and width of the carriageway, the speed limitation of the accident sections and accidents delay time.

(1) The number of closed lanes near the accident point
After the accident, for security requirements and required space of on-site processing, sometimes it is necessary to close one or more lanes. That will greatly reduce the capacity of urban road, leading to traffic congestion and obstruction.

(2) The length and width of the carriageway
The longer the length of the closed lane, the lower travel speed in the lane and lane changing, and that also reduces the capacity of the accident sections. The width of the carriageway near accident point will also have a certain impact on the capacity of the accidental road.

(3) The speed limitation of the accident roads
The speed is limited in the unclosed lane. Limited speed can improve its safety through it and balanced traffic low speeds, reducing secondary accidents, but its capacity will be reduced.

(4) The accident delay time
The accident delay time is related with operating strength, types of accidents, severity, traffic conditions and other factors. The stronger the operating strength, the shorter the accident delay time, its capacity recoveries sooner.

For influencing factors of the capacity of special accident roads, for example, tunnels, bridges, in addition to the above factors, there are other special influencing factors. The capacity of tunnels is related to lighting intensity, traffic signs of the tunnel entrance and other factors; However, the bridge is related to slope and linear.

4. The capacity analysis of urban expressway about traffic accident

Taking into account influencing factors of urban expressway capacity under different accident types, accident delay time will vary. Use the information gain values based on ID algorithm of the decision tree to estimate the delay time for different accident types of urban Expressway, the formula is as follows:

$$Gain(S, A) = Entropy(S) - \sum_{v \in \text{Value}(A)} \frac{|S_v|}{|S|} \cdot \text{Entropy}(S_v)$$

Where:
\[ \text{Entropy}(S) = -\sum_{i=1}^{m} p(u_i) \log p(u_i) \] (2)

\( S \) = Sample collection; \( \text{Entropy}(S) \) = Information entropy; \( p(u_i) \) = Probability of Category \( i \); \( A \) = Property; \( \text{Value}(A) \) = The collection of the value of the property \( A \); \( v \) = a value of the property \( A \); \( S_v \) = sample collection that the value of the property \( A \) is \( v \); \( |S_v| = S_v \) contains sample number.

Select the Xi’an loop accident as samples, according to the above formulas, accident delay time of common accident types on the expressway is calculated as shown in Table 1.

### Table 1: Accident delay time of common accident types on expressway

<table>
<thead>
<tr>
<th>Types of accidents</th>
<th>The accident delay time (average) /min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor (the vehicles cannot move)</td>
<td>15</td>
</tr>
<tr>
<td>Anchor (the vehicles can move)</td>
<td>7</td>
</tr>
<tr>
<td>Roll-over (vehicle type are cars, no casualties)</td>
<td>33</td>
</tr>
<tr>
<td>Roll-over (vehicle type are cars, injuries)</td>
<td>48</td>
</tr>
<tr>
<td>Fire (vehicle type are cars, no casualties, no damage to the facility)</td>
<td>18</td>
</tr>
<tr>
<td>Fire (vehicle type are cars, no casualties, damage to the facility)</td>
<td>36</td>
</tr>
<tr>
<td>Rear-end (the number of related vehicles ≥ 3, vehicle type are cars, no casualties)</td>
<td>23</td>
</tr>
<tr>
<td>Rear-end (the number of related vehicles ≥ 3, the vehicle type are cars, injuries)</td>
<td>49</td>
</tr>
<tr>
<td>Collision (casualties but no deaths, vehicle type are cars)</td>
<td>37</td>
</tr>
<tr>
<td>Collision (casualties but no deaths, vehicle type are bus)</td>
<td>59</td>
</tr>
</tbody>
</table>

The dissipation time can obtained from the Flow Wave Theory, the calculation formula as follows:

\[ Q_{w1} = (v_2 - v_1)/(1/K_2 - 1/K_1) \] (3)

\[ Q_{w2} = (v_3 - v_2)/(1/K_3 - 1/K_2) \] (4)

\[ t_s = t_A (Q_{w1}/(Q_{w2} - Q_{w1})) \] (5)

Where:

- \( Q_{w1} \) = the wave flow of Build-wave;
- \( Q_{w2} \) = the wave flow of Evanescent wave;
- \( v_3 \), \( v_2 \), \( v_1 \) = the speeds of the three kinds of traffic state;
- \( K_3 \), \( K_2 \), \( K_1 \) = the density of the three kinds of traffic state;
- \( t_A \) = The accident delay in time;
- \( t_s \) = Crowded dissipation time.

The entire process of urban expressway from traffic congestion to dissipate under traffic accident influence is shown in Figure 3.
Figure 3 shows that the reciprocal of the ratio (slope) between the accident delay time and cumulative number of vehicles in the time period is the capacity under traffic accident; the reciprocal of the ratio (slope) between congestion dissipation time and cumulative number of vehicles in the time period is recovery capacity of the state (it slightly is less than the capacity of actual road). This article only discusses the former and accidents take place on urban expressway.

5. The simulation analysis of the capacity on urban expressway under unexpected traffic accident

According to the theoretical analysis of urban expressway capacity under unexpected traffic accident, use Vissim simulation software to simulate and estimate for its capacity under traffic accident. We obtain multiple values through the multi-group simulations, then, take the average value in order to reduce the error. The simulation analysis of the capacity on urban expressway under unexpected traffic accident is shown in Figure 4.
5.1 Set up road conditions and accident type

The road conditions are divided into road grade, travel direction, whether there is a separation zone, numbers of two-way lanes, lane width, etc. There are also many different accident types, for example, vehicle collision, vehicle fire, lane position where the accident occurred, number of closed-lanes. This article takes a closer-left lane based on 3 lanes as an example to research.

5.2 Set up traffic volume conditions

Traffic volume conditions include traffic composition, the proportion, traffic volume, speed, etc. Expectation speed curve of the road under the different road levels is set in accordance with the "urban road design specifications".

The vehicle composition and expectation speed distribution of the car is shown in Figure 5 and Figure 6.

5.3 Set up the simulation parameters

The related parameters setting as shown in Table 2 and Table 3:

**Table 2:** The vehicle classification and conversion coefficient

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Passenger car</th>
<th>The bus</th>
<th>Truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>The proportion of vehicle components</td>
<td>84.00%</td>
<td>3.00%</td>
<td>13.00%</td>
</tr>
<tr>
<td>Reference conversion coefficient</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
</tr>
</tbody>
</table>

Note: urban expressway simulation settings, passenger cars (including small trucks); bus (including medium-sized passenger); truck (including big bus, medium-sized trucks and large trucks)

**Table 3:** Signal control parameters setting under different accident types

<table>
<thead>
<tr>
<th>Name</th>
<th>Red/Amber</th>
<th>Amber</th>
<th>Red End</th>
<th>Green End</th>
<th>Red End2</th>
<th>Green End2</th>
<th>Type</th>
<th>Cycle time(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor</td>
<td>0</td>
<td>0</td>
<td>1080</td>
<td>2400</td>
<td>—</td>
<td>—</td>
<td>Cycle</td>
<td>2400</td>
</tr>
<tr>
<td>Roll-over</td>
<td>0</td>
<td>0</td>
<td>2160</td>
<td>3600</td>
<td>—</td>
<td>—</td>
<td>Cycle</td>
<td>3600</td>
</tr>
</tbody>
</table>
Because there are no simulation modules of traffic accidents in Vissim simulation software, this article sets up red light on the accident lane to simulate for traffic accidents. The signal begins to turn red when the accidents happened, and won’t turn green until the end of the accident.

5.4 The simulation result and analysis

This article selects a part of the accident types. We achieve an effect of the simulation through specific parameters setting, calculation models of accident delay time and Flow Wave (the free flow speed is 80km/h, blocking density is 106vehicle/km), simulation results as shown in Figure 7, the simulation data is shown in Table 4.

![Figure 7: Simulation effect diagram](image)

Table 4: The simulation result by VISSIM

<table>
<thead>
<tr>
<th>Type of accident</th>
<th>$t_d$</th>
<th>$t_s$</th>
<th>$t_s/t_d$</th>
<th>$N_1$</th>
<th>$N_2$</th>
<th>$C_r$</th>
<th>$n$</th>
<th>$C_s$</th>
<th>$C$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor (the vehicles cannot move)</td>
<td>15</td>
<td>3.5</td>
<td>0.23</td>
<td>732</td>
<td>944</td>
<td>3776</td>
<td>3</td>
<td>1800</td>
<td>5400</td>
<td>69.926</td>
</tr>
<tr>
<td>Roll-over (vehicle type are cars, no casualties)</td>
<td>33</td>
<td>46.2</td>
<td>1.4</td>
<td>1309</td>
<td>1689</td>
<td>3071</td>
<td>3</td>
<td>1800</td>
<td>5400</td>
<td>56.870</td>
</tr>
<tr>
<td>Fire (vehicle type are cars, no casualties, no damage to the facility)</td>
<td>18</td>
<td>10</td>
<td>0.56</td>
<td>774</td>
<td>998</td>
<td>3327</td>
<td>3</td>
<td>1800</td>
<td>5400</td>
<td>61.611</td>
</tr>
<tr>
<td>Rear-end (the number of related vehicles $\geq$ 3, vehicle type are cars, no casualties)</td>
<td>23</td>
<td>18.4</td>
<td>0.8</td>
<td>960</td>
<td>1238</td>
<td>3229</td>
<td>3</td>
<td>1800</td>
<td>5400</td>
<td>59.796</td>
</tr>
<tr>
<td>Collision (casualties but no deaths, vehicle type are cars)</td>
<td>37</td>
<td>51.7</td>
<td>1.40</td>
<td>1290</td>
<td>1664</td>
<td>2698</td>
<td>3</td>
<td>1800</td>
<td>5400</td>
<td>49.963</td>
</tr>
</tbody>
</table>
Notes: Accident delay time—\( t_A \) (min); Crowded dissipation time—\( t_s \) (min); Cumulative number of vehicles—\( N_1 \) (vehicle); Cumulative number of standard vehicles—\( N_2 \) (pcu); Residual capacity of accident roads—\( C_R \) (pcu/h); number of lanes—\( n \); One Lane capacity—\( C_S \) (pcu/h); The proportion of residual capacity of accident roads—\( \beta \) (%) ; \( C \)—One-way road capacity.

Table 6 shows that the accident delay time of vehicle anchor and the crowded dissipation time are the minimum, but residual capacity of accident roads is the maximum, the portion is 69.926%; the accident delay time of vehicle collision and the crowded dissipation time are the maximum, but residual capacity of accident roads is the minimum, the proportion is 49.963%; the proportion of the vehicle roll-over, fire and rear-end residual capacity are 56.87%, 61.611%, 59.796% respectively.

6. Conclusions

The ratio between crowded dissipation time and accident delay time will affect residual capacity of accident roads: the bigger residual capacity, the smaller the ratio; conversely, the greater. According to the different types of traffic accidents, through the simulation and research for the urban expressway capacity, this paper can provide decision support for urban traffic management departments take appropriate response measures. However, different locations and time of the traffic accident has a great influence on the capacity of urban expressway, still need further research.

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