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Estimation of Traffic Incident Delay and its Impact Analysis Based on Cell Transmission Model

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Abstract—**Effective incident management and traffic control measurements require a full understanding of the characteristics of incidents to accurately estimate incident durations and to help make more efficient decisions to reduce the impacts of non recurring congestion due to these accidents. The Incident duration consist of four elements: detection time, response time, clearance time and recovery time. This paper develops a recovery model and incident delay model based on CTM, which has analytical simplicity and the ability to reproduce the traffic behavioral. Impact analysis of recovery time and incident delay have been done in quantity to demonstrate recovery time and delay during recovery time can not be neglected because it often accounts for larger proportion of the duration time and total delay especially in the city freeways. Accurate estimation of traffic incident delay is helpful to effective incident management and traffic control.**

I. INTRODUCTION

Traffic congestion and the delays are significant problems in most large urban areas, which is not only coursed by daily congestion but also caused by non recurring congestion, such as traffic accidents, vehicle disablements, and road construction. Shanghai is one of the largest cities in China. With the economic development, traffic volume increases rapidly, while traffic conditions deteriorate day by day. Traffic incidents make the current traffic condition even worse and have bad influence to people's daily life. Much more attention has to be paid to the traffic incident management. Traffic incident duration prediction is the key problem of traffic incident management. Estimation of traffic incident delay during the whole incident duration time is very important in Advanced Traffic Incident Management (ATIM). The duration of an incident is composed of four phases [1]: detection time, response time, clearance time and recovery time which is shown in Fig.1. In the detection phase, the location, severity, and injuries of the incident are identified by the traffic managers, police, or patrol members. In the response phase, instrumented vehicles arrive at the incident site to handle the incident. In the clearance phase, the response team removes the obstacle that disturbs the traffic movements. In the recovery phase, the queue starts to resolve until the traffic restored to normal conditions. The first three phases are called incident time. The recovery time is one part of the total duration time which, however, is seldom taken that into account in most researches. The durations and delay should be as accurate as possible not only for better decision-making but also for releasing reliable congestion information to drives.

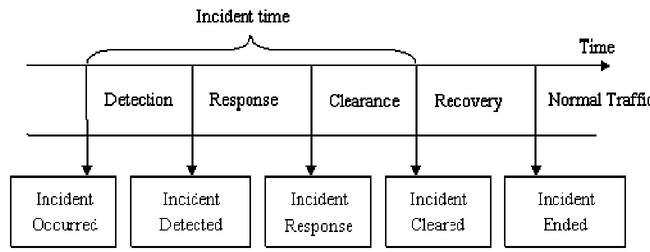

FIGURE 1. Duration of Traffic Incidents.

Some helpful work related to incident duration time has already been done. It was the first time for Golob et al. [2] to research the traffic incident duration time based on statistical distribution and divided the duration time into four parts. Giuliano[3] investigated the major impact factors of incident duration time such as incident types, occurrence time and presented the prediction model based on statistical distribution. Wang[4] set up incident clearance time prediction model based on linear regression model using 121 traffic incident data in Chicago area. But the precision and efficiency of the model had not been mentioned. Khattak et al.[5] put forward a clearance time prediction model based on time sequential model and they found that the most significant impact factors of clearance time were incident type and severity. Smith[6] developed a clearance time prediction model based on a non parametric regression model using 6828 traffic incident data of STL laboratory in university of Virginia, however, average error was large and the model were not suggested to be applied into the traffic incident management. Ji Yang[7] gave a clearance time prediction model based on a Bayesian decision model which used the information about the incident as much as possible and results show that model has a higher precision comparing other prediction methods. Even though many of researches dealt with traffic incident time prediction, the recovery time was not included. Though Zeng[8] indicated recovery time is crucial to determine the incident-induced delay, and forward an empirical method for estimating traffic incident recovery time by comparing the segment travel time under incident condition with background travel time profile using statistics, this method which is based

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on real data in the whole period can not be used on-line or model prediction.

Traffic delay especially during recovery time can not be neglected, which sometime accounts for larger proportion comparing the incident time. Therefore, we propose here to develop a new model to predict traffic recovery time after an incident has been cleared and traffic delay during incident time and recovery time respectively. Based on this model, impact factors of incident-induced delay analysis will be done in quantity.

Firstly, we start with an overview of the state-of-the-art of prediction model of incident duration time and incident delay. Secondly, the methodology of incident duration time and delay is described in detail. And the model calibration method, the model parameters and the model precision of the recovery time are introduced. The calculation of incident-induced delay and impact factors analysis are researched in section 3. Section 4 gives conclusions and suggestions for further work.

II. METHODOLOGY

A. Cell Transmission Model (CTM)

The CTM is a macroscopic model with analytical simplicity, dynamic and real parameters, and it has the ability to reproduce dynamic traffic behavioral phenomena, the model has been first presented by Daganzo[9,10]. The solution of CTM is easier than the differential equations of the LWR (Lighthill、Whitham and Richards) model. Hence, a CTM has been selected for this research. In CTM models, the road sections are divided into a series of cells, on the assumption that the relationship between flow and density is in the shape of an isosceles trapezoid, as in Fig.2, where k_{jam}, Q, V, W denote, respectively, the jam density, maximum allowable inflow, free-flow speed, and speed of the backward shock wave. Then, inflow in a cell can be expressed as the function of these variables:

$$f = \min\left\{Vk, Q, W(k_{jam} - k)\right\} \tag{1}$$

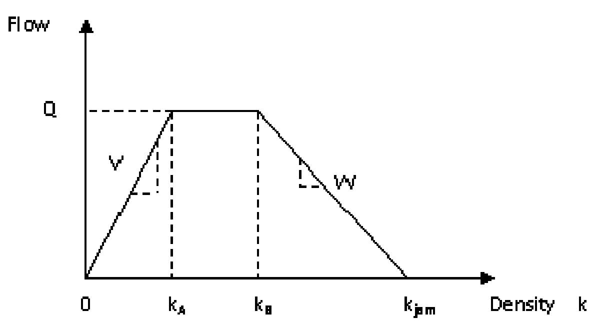

FIGURE 2 Trapezoidal fundamental diagram.

The core concept of CTM is to discretize the road into homogenous cells (shown in Fig.3) and time into intervals such that the cell length is equal to the distance traveled by free flowing traffic in one time interval. Then the CTM is based on a recursion where the cell occupancy at time *t+1* equals its occupancy at time *t*, plus the inflow and minus the outflow shown in Eq.2, where the flows are related to the current conditions at time t as indicated in Eq.3.

$$n_i(t+1) = n_i(t) + f_i(t) - f_{i+1}(t) \tag{2}$$

$$f_i(t) = \min\left\{n_{i-1}(t), Q_i(t), (W/V)\left[N_i(t) - n_i(t)\right]\right\} \tag{3}$$

$f_i(t)$, the actual inflow of cell i； $n_i(t)$, the number of vehicles waiting to enter cell i＋1;

$N_i(t)$, the maximum number of vehicles allowable in cell i at time t;

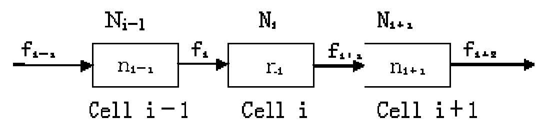

FIGURE 3 The CTM basic building block

B. The Cell-based Traffic Incident Representation

When an incident occurred between cell *i* and cell *i-1* on the link *j* (Fig.4), properties of cell *i* and cell *i-1* have to be changed. The inflow capacity and congestion density in cell *i* and cell *i-1* will be reduced to *Q'*, k'_{jam} and the *W* also will be changed to *W'*, thus the Q-k relationship in cell *i* and cell *i-1* is shown in Fig.5 where there is an incident. *Q'*, k_{jam}' and *W'* are variables depending on the incident type, severity and duration time.

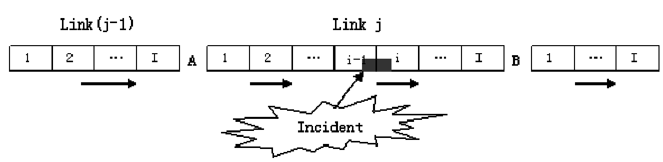

FIGURE 4 The CTM with incident on the road

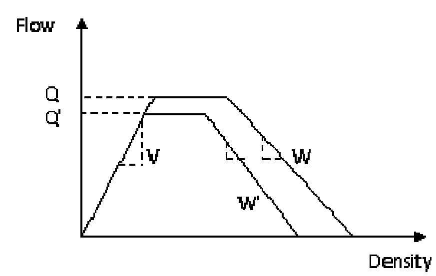

FIGURE 5 Q-k reduction with incident occurred

C. CTM Parameters Determination

Elevated freeways in Shanghai city undertake very high traffic volumes, thus the traffic congestion phenomena frequently appeared on these elevated freeways. Consequently, the efficiency of freeways decreased obviously and the delay on the freeways increased. Incidents are major contributors to congestion and delay. The statistical data shows an average 63 vehicle breakdowns in normal weather conditions, 80 vehicle breakdowns in bad weather and 20 accidents in one day. Therefore, 4 kilometers of elevated freeway with two lanes were selected as an example to develop a recovery time model (shown in Fig.6). Double loop detectors are located on the freeway, and the distance between them is also showed in Fig.6.

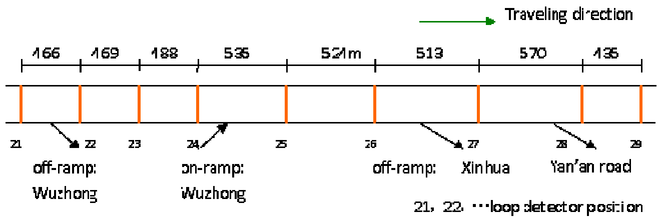

FIGURE 6 Road segment in elevated freeways in Shanghai city

The main inputs of CTM include the freeway geometry, model parameters, traffic demand at each entrance and the simulation step[11]. Most of the traffic data used in the model calibration was obtained from the management centre of elevated freeways. Each freeway loop detector provided speed, density and occupancy every 20 seconds. The main parameters of CTM are as follows which has been calibrated[12].

Free-flow traffic speed is determined by performing a least square fit on the real flow versus density data over 5:00-6:00AM, and the range between 70km/h~80km/h are chosen as free-flow speed on this segment.

By examining contour plots of observed flow and speed, the capacity of non bottleneck should be equal to the maximum flow at each detector-equipped cell. In this research, 1900 vehicles/hour/lane is determined as capacity of non bottleneck by applying a capacity estimation method.

The capacity of the bottleneck is identified by loop detectors when an accident occurred on the freeways. The capacity reduction can be calculated by comparing the capacity before and after the incident occurred, which is not only dependent on the road situation but also on the accident characteristics.

The simulation time step is 10 seconds and the segment is divided into 20 cells with the length of each cell is equal to 200 meters. Based on model calibration method described above, the model parameters are determined as follows: the capacity is 3600 vehicles/h for two lanes, free flow speed is 72km/h, and congestion density is 240 vehicles/km for two lanes. Thus the maximum inflow of each cell in each interval is 10 vehicles and the number of vehicles allowed in one cell is 48 vehicles, then $k_{jam} = 48$, $k_a = 10$, $k_b = 24$.

III. INCIDENT-INDUCED DELAY AND ITS IMPACT FACTORS ANALYSIS

The following factors such as capacity reduction, recovery time, traffic demand upstream of traffic incident, clearance efficiency of incident, play a significant role in traffic recovery time and duration time; therefore impact the total incident-induced delay. Estimating these impact factors on traffic delay in quantity, especially the comparing analysis of traffic delay during incident time and recovery time, is quite helpful for improving and evaluating incident management efficiency and traffic control strategy.

Approach delay (in time steps) $d_i(t)$ accrued in cell i at time t within this cell-based network representation can be estimated at the cell level by subtracting a cell's out flow from its occupancy for each time step[13] as shown in Eq.4.

$$d_i(t) = \left[n_i(t) - f_{i+1}(t)\right]\left[(t+1) - t\right] = n_i(t) - f_{i+1}(t) \qquad (4)$$

In above equation, a delay of one time step is defined as any existing traffic in a cell that can not leave in the next time step. The unit of $d_i(t)$ is thus in vehicle·time. For time steps of 10 seconds in this model, its unit is 10 vehicle·seconds. In light traffic, when the outflow $f_{i+1}(t)$ from cell i at time t is unrestricted by the downstream cell $i+1$, that means all traffic in cell i can leave in the next cell $i+1$ (i.e., $f_{i+1}(t)=n_i(t)$), thus there is no delay. In the case that the downstream cell $i+1$ has an inflow restriction that is smaller than $n_i(t)$, the part of traffic that can not leave cell i at time t encounters a delay as defined in equation (4) during the time interval from t to $t+1$.

A. *The Influence of Capacity Reduction*

The more capacity reduction induced by the traffic incident at the same incident time is, there will be the longer congestion queue and accordingly the longer recovery time it will be after clearance. How much the impact of capacity reduction on recovery time and the total delay during the whole incident duration time is investigated firstly. It is assumed there are 4 levels of capacity reduction which are 0%, 30%, 50% and 70% of the original capacity respectively. Traffic demand upstream the incident is assumed as 80% capacity to simulate normal traffic condition in daytime in Shanghai.

Fig.7 shows the ratio of recovery time and incident time at different capacity reduction levels, which are 0%, 30%, 50% and 70% separately. Different marks represent different incident time such as 5 minutes, 10 minutes. The ratio of recovery time and incident time increases significantly with the larger capacity reduction. For example, the ratio of recovery time and incident time is 0.35 when incident time is 20 minutes, indicating recovery time is less than incident time, while this ratio increase to 1.15 at same incident time because of more capacity reduction, which means the recovery time is greater than incident time. Therefore, recovery time can not be neglected but should be paid much more attention in traffic analysis and management on some occasions.

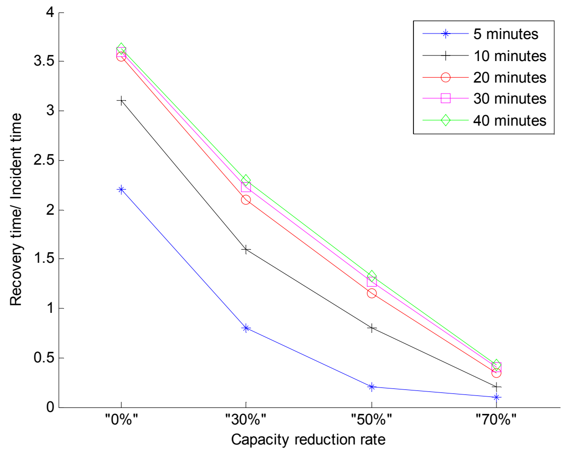

FIGURE 7 The ratio of recovery time and incident time at four different capacity reduction level, that is 0%, 30%, 50% and 70%.

By analysis of variance (ANOVA), the p-value indicates both incident time and capacity reduction have influence on the ratio of recovery time and incident time, and capacity reduction plays more role in that ratio than incident time (shown in Table 1).

Table 1
ANOVA of incident time and capacity reduction on ratio of recovery time and incident time

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
Incident time	3.3518	4	0.83794	15.92	9.62E-05
Capacity reduction	23.8704	3	7.95679	151.15	8.52E-10
Error	0.6317	12	0.05264		
Total	27.8538	19			

Traffic incident-induced delay of each capacity reduction differs with incident time as shown in Fig.8, in that figure different mark indicates different incident time. The figure indicates that the delay increase sharply with the increase of incident time. For an instance, if incident time increases from 5 minutes to 10 minutes when capacity reduction is 50%, the total delay increases more than 20 times (from 32 minutes to 782 minutes). This is because the traffic demand assumed here is great and much more vehicles will suffers delay upstream incident without any traffic control or getting incident information.

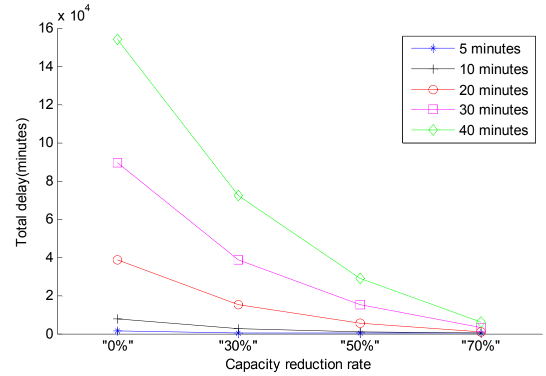

FIGURE 8. Total delay of each capacity reduction rate at different incident time

B. *The Influence of Incident Time*

It is clear shown in Fig.9 that ratio range of average congestion delay (which is the average delay during incident time) and average recovery delay (which is during recovery period after incident is cleared) at different capacity reductions is almost from 80% to 120%, assuming traffic demand upstream incident is 80% of capacity. Therefore, not only can the average delay not be neglected; the average recovery delay is sometime even greater than average congestion delay. With the increase of incident time, the ratio tends to equal one, which means the recovery delay is almost same as the congestion delay in such situation.

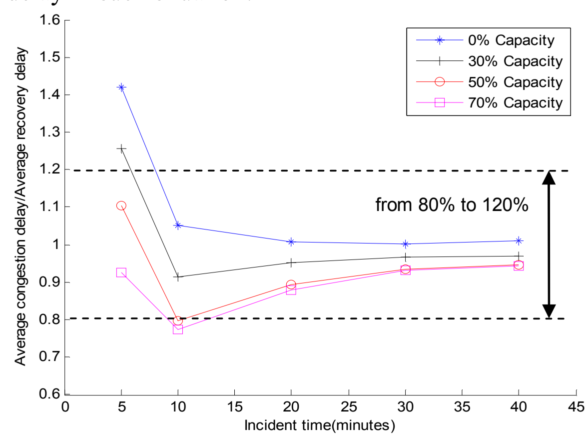

FIGURE 9 Relationship between ratio of average congestion delay and average recovery delay and incident time at different capacity reduction.

In the Fig.10, different line indicates traffic demand, for example 60% demand means the demand equals 60% of capacity. Traffic demand has nearly no influence on the ratio of average congestion delay and average recovery delay as shown in the Fig.10. The relationship lines of this ratio and incident time almost overlap at different demand.

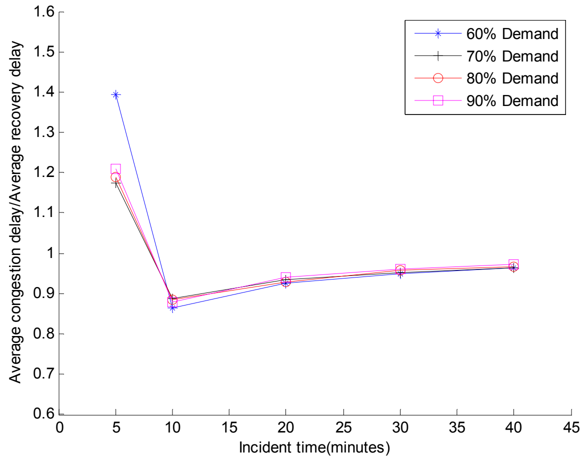

FIGURE 10 Relationship between ratio of average congestion delay and average recovery delay and incident time at different traffic demand

C. *The Influence of Traffic Demand*

In the Fig.11, different mark means different incident time, such that line with circles indicates the incident time is 20 minutes. The recovery time double and redouble with the increase of traffic demand as shown. The more traffic demand or the longer incident time, the longer recovery time will be. Since recovery time double, the recovery delay also double and redouble as shown in the Fig.12.

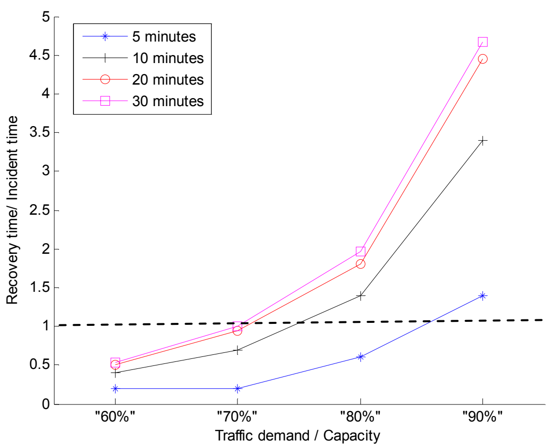

FIGURE 11 Relationship between ratio of recovery time and incident time and traffic demand at different capacity reduction

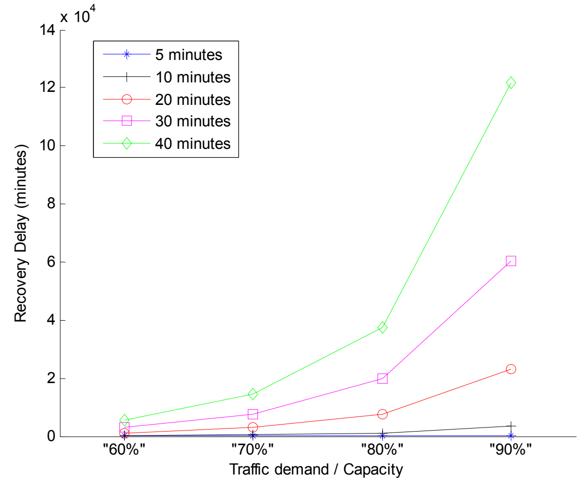

FIGURE 12 Relationship between ratio of recovery time and incident time and traffic demand at different capacity reduction

The Table 2 shows both traffic demand and incident time have impact on the recovery delay. However, traffic demand plays more significant influence on the recovery delay than incident time. Therefore, it is important to implement traffic demand control, for example, to release traffic incident information upstream incident location to inform driver change another route or departure time in order that the traffic demand can be reduced. Accordingly the delay caused by incident can also be reduced.

Table 2
ANOVA of traffic demand and incident time on ratio of recovery delay

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
Traffic demand	4.93e+009	3	1.64e+009	3.37	0.0446
Incident time	5.59e+009	4	1.40e+009	2.86	0.0704
Error	5.85e+009	12	4.88e+009		
Total	1.64e+009	19			

D. *The influence of saving clearance time*

The Fig.13 shows the relationship between reduced clearance time and reduced recovery time. Four kinds of incidents were simulated, “40-0%” means the incident time is 40 minutes and the capacity is 0% of original capacity; “40-50%” means the incident time is 40 minutes and the capacity is 50% of original capacity; “20-0%” means the incident time is 20 minutes and the capacity is 0% of original capacity; “20-50%” means the incident time is 20 minutes and the capacity is 50% of original capacity. The reduced recovery time is linear related with the reduced clearance time. If 5 minutes in advance to clear the incident for that incident lasts 40 minutes and the capacity is only 0% of original, the recovery time will decrease 23 minutes that means decease 15.8%.

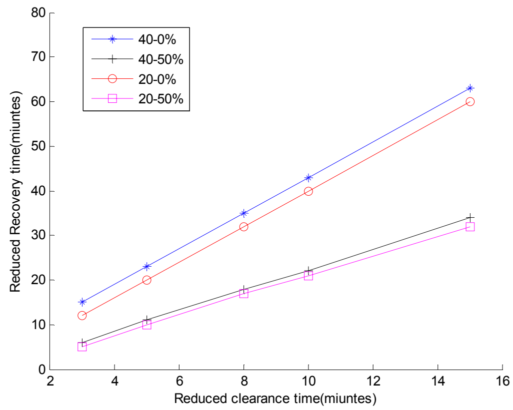

FIGURE 13 Relationship between reduced clearance time and reduced recovery time.

The relationship of reduced delay and reduced clearance time is shown in Fig.14. The reduced delay is also linear related with reduced clearance time and more gradient than the Fig.13. So if 5 minutes in advance to clear the incident for the same incident that lasts 40 minutes and the capacity is only 0% of original, the delay will decrease 26%. If 8 minutes in advance for the same incident, the delay will decrease 40%. Therefore clearing the incident as soon as possible will significantly decrease delay.

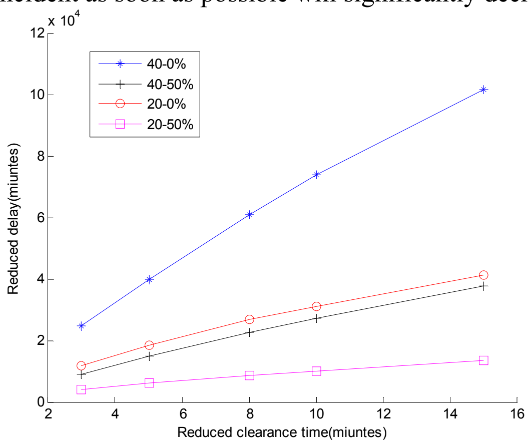

FIGURE 14 Relationship between reduced clearance time and reduced delay

IV. Conclusions

Recovery time prediction model and incident delay model based on the CTM was developed in this paper. Impact factors analysis of recovery time and incident-induced delay have been done in quantity. The following conclusions have been drawn:

1. Recovery time can not be neglected because it is sometime more than the incident time in some occasions. Both incident time and capacity reduction have significantly influence on the ratio of recovery time and incident time, and capacity reduction plays more role in the ratio than incident time by ANOVA.

2. The delay increase sharply with the increase of incident time, and sometime even increases more than 20 times in special cases, for example when the traffic demand is great and much more vehicles will suffers delay upstream incident without any traffic control or getting incident information.

3. The ratio range of average congestion delay and average recovery delay at different capacity reductions is almost from 80% to 120%, and with the increase of incident time, the ratio tends to equal 1. Traffic demand has nearly no influence on this ratio. This indicates the delay after the incidents have been cleared can not be neglected any more.

4. The recovery time double and redouble with the increase of traffic demand. Both traffic demand and incident time have impact on the recovery delay. However, traffic demand plays more significant influence on the recovery delay than incident time.

5. The reduced delay is linear related with reduced clearance time. Clearing the incident as soon as possible will significantly decrease delay.

In the future, more research can be investigated based on this model, such as what kind of traffic control method should be implemented to incidents and which kind of traffic management method is much more efficient.

References

[1] (FHWA), F.H.A. FRESIM user guide[J]. Version 4.5, Ofc. Of Res. and Devel., US. Dept. of Transp., Washington D.C., 1994.
[2] Golob, T.F., Wilfred W. Recker and John D. Leonard. An Analysis of the Severity and Incident Duration of Truck-Involved Freeway Accidents[J]. Accident Analysis & Prevention, 1987, 19(4).
[3] Giuliano, G. Incident characteristics, frequency, and duration on a high volume urban freeway[J]. TRANSP. RES., 1989, 23(5): 387-396.
[4] Wang, M. Modeling freeway incident clearance time MS thesis[J]. Civil Engineering Dept, Northwestern University, 1991.
[5] Khattak, A.J., J.L. Schofer, M.H. Wang. A SIMPLE TIME SEQUENTIAL PROCEDURE FOR PREDICTING FREEWAY INCIDENT DURATION[J]. Journal of Intelligent Transportation Systems, 1995, 2(2): 113-138.
[6] Smith, K.W. A Research Project Report For the National ITS Implementation Center: Forecasting the Clearance Time of Freeway Accidents [D]. University of Virginia, 2001.
[7] Ji Yang Beibei. Research on Prediction Method of Traffic Incident Duration. PHD thesis. TongJi University. ShangHai 61- 84. 2007.
[8] Zeng Xiaosi, Songchitruksa, Praprut. Empirical Method for Estimating Traffic Incident Recovery Time. 89th Transportation Research Board [C]. 10-3934. 2010
[9] Daganzo, C.F. The cell transmission model: a dynamic representation of highway traffic consistent with the hydrodynamic theory[J]. Transportation Research A, 1994, 24(B)(4).
[10] Daganzo, C.F. The cell transmission model, Part II: Network traffic[J]. Transportation Research, 1995, 29(B)(2).
[11] Laura Munoz, X.S., Dengfeng Sun, Gabriel Gomes, Roberto Horowitz. Methodological Calibration of the Cell Transmission Model[J]. Proceeding of the 2004 American Control Conference Boston, Massachusetts June30-July 4, 2004.
[12] Yangbeibei Ji, Winnie Daamen, Xiaoning Zhang, Lijun Sun. Traffic incident recovery time prediction model based on Cell transmission Model. Proceedings of the 12th International IEEE Conference on Intelligent Transportation Systems, St. Louis, MO, USA.
[13] Hong K. Lo, Elbert Chang, Yiu Cho Chan, Dynamic network traffic control. Transportation Research Part A 35 (2001) 721-744.