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Influence range of emergency under special events based on CTM

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Abstract: To determine the dynamic influence range of emergencies under special events, the spacial and temporal characteristics of the traffic flow are studied by simulation based on the cell transmission model (CTM). Based on the traffic management measures used under special events, a semi-dynamic assignment algorithm is proposed, which is combined with an algorithm for logit multi-path traffic assignment and the CTM. In a simple calculation network, the spacial and temporal characteristics of traffic flows which vary with different traffic management schemes are studied, and a method to obtain the influence range of emergency is proposed by computing the jam time of the intersections. By contrasting the average delay of each vehicle, the dissipation effect is studied under two different traffic management schemes. The example shows that the spatial and temporal variety of the traffic flow can be easily simulated and the influence range of emergency can be confirmed by the method based on the CTM. The proposed method provides a new idea for decision-making on traffic management under emergency under special events.

Key words: traffic management; special event; emergency; influence range; cell transmission model (CTM)

Special events occurring frequently imposes heavy pressure on urban traffic management, and awareness of the dynamic characteristics of the traffic flow is the basis of the traffic management scheme[1]. Traffic demand is highly centralized in time and space especially in the dissipation process under special events. Once an emergency occurs, a significant number of vehicles will be generated in a short time, which requires an effective management scheme to reduce the influence of the emergency and resume the traffic on line as soon as possible. Based on the cell transmission model (CTM), a semi-dynamic assignment algorithm is proposed by simulating the variation influence range of emergencies, which applies an effective evaluation method to different advanced management schemes for emergencies under special events.

1 Cell Transmission Model

The CTM was first proposed by Daganzo[2] in 1994. By citing the relationship of the traffic flow f and the traffic density k, Lighthill et al. [3-4] simplified the solving method of LWR:

$$f=\min\{Vk,\ Q,\ W(k_{\mathrm{j}}-k)\} \tag{1}$$

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where k_{j}, Q, V, W are the jam density, the incoming flow, the free flow speed and the shock wave speed, respectively. By dividing the road into many equidistant cells, and dividing the time into equal segments (The distance of a cell equals the running distance at free flow speed in each time segment), the LWR can be discretized as

$$n_j(t+1)=n_j(t)+f_j(t)-f_{j+1}(t) \tag{2}$$

$$f_j(t)=\min\{n_{j-1}(t),Q_j(t),\frac{W}{V}[N_j(t)-n_j(t)]\} \tag{3}$$

where the subscript j represents the cell j; $j+1$ and $j-1$ represent the upriver one and the downriver one of cell j, respectively; $n_j(t)$, $f_j(t)$, $N_j(t)$ are the vehicle number, the inflow vehicle number and the maximal capability in cell j in segment time t, respectively.

The relationship of different cells is prescribed in detail in the CTM[5]. The CTM can describe the physical characteristics of queuing and other dynamical characteristics of the traffic flow[6], such as shock wave, queuing forming, queuing dissipation and mutual dynamic influence among multi-links, so the CTM can characterize the unsaturated flow, the saturated flow and the congested flow. Taking its characteristics into account, the CTM is selected to simulate the traffic flow under emergency. Though the model ignores the differences among vehicles, it reflects the macroscopical characteristics of the traffic flow and it satisfies the precision of engineering practice.

2 Expression of Emergency in Model

An emergency is defined as $E(E_{\mathrm{c}}, L_{\mathrm{e}}, t_0)$, where E_{c} is the emergency type, L_{e} is the number of the cells where the emergency appears, and t_0 is the start time of the emergency. By inputting the emergency information into the decision-making system, some time parameters can be obtained, such as detecting and receiving time T_1, disposing time T_2 and controlling time T_3, etc. (see Fig. 1). In Fig. 1, emergency starts at t_0, emergency is detected at t_1, policemen arrive at t_2, controlling measures are carried into execution at t_3, emergency ends at t_4 and controlling measures end at t_5.

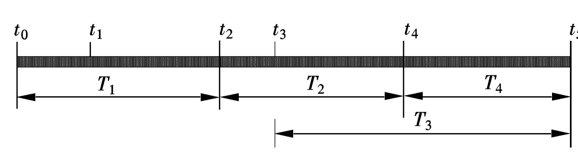


Fig. 1 Emergency disposing timetable

According to the place of events occurring in the network, traffic emergencies can be divided into three types: link emergency, intersection emergency and area emergency[7]. In this research, three types of emergency can be transformed into link emergency. When the emergency occurs in the link, the admittance flow of the emergency cell is adjusted, $Q_{j,i}(t) = 0$. When the traffic resumes, $Q_{j,i}(t)$ is adjusted to the quondam value. By adjusting $Q_{j,i}(t)$ in the CTM, the numbers of vehicles in cell j and outflow vehicles from cell j of link i in period time t, namely $n_{j,i}(t)$ and $f_{j+1,i}(t)$, can be calculated. According to the above analysis, we can obtain the numbers of vehicles in the link i and outflow vehicles from link i, which reflects the spacial and temporal varieties of the traffic flow.

An intersection emergency can be regarded as several link emergencies, or it can be realized by adjusting the capability of the cells which are used to control the signals in the model. Similarly, an area emergency can be divided into many link emergencies and intersection emergencies near the boundaries of the area.

3 Expression of Traffic Management Measures in Model

Traffic controlling and management measures include reallocating lanes and drawing volume[8]. In the CTM, reallocating lanes are realized by changing the attributes of the cells in the link. For example, when an emergency occurs on a two-way, three-lane road at t_3, the occupied lane in the main direction of the flow is closed, and one lane in the opposite way will be adjusted to replace the occupied lane to expedite the main flow. Then only two lanes are left for the opposite flow. The adjustment will continue for a period of time T_3. Except for adjusting the acceptable volume of the cell, the relationship of inflow and outflow on the alter-direction lane should be adjusted, which is related to the relationship of inflow and outflow of the two intersections connected by the lane.

The measure of drawing volume is realized by limiting the turning proportion in the intersection. For example, once a certain direction of the flow is forbidden, the turning proportion of this direction is temporarily adjusted to 0. If only one direction of the flow is allowed to pass, the turning proportion of this direction is adjusted to 1. If no direction of the flow is forbidden, the turning proportion in the intersection varies for the personal path-selection action affected by the traffic flow in the whole network. So it is necessary to study the traffic assignment under emergency.

4 Traffic Assignment under Emergency

Once an emergency occurs in the dissipation of special events, a traffic jam is unavoidable and an equilibrium state in the road network is broken for a period of time. The decrease in capacity and the implementation of traffic management measures will change the impedance of the link and the flow distribution in the whole network. For the period of time which is from the start of the emergency to the normal resumption of the network flow, it is necessary to reassign the traffic flow and know the variations in the turning proportions of the intersections.

The dissipation process of special events always covers a short period of time, so the assignment result needs to be quickly obtained to describe the variations in the flow in a timely manner, which needs a simple method to solve the problem. Combined with the characteristics of the CTM, a semi-dynamic assignment method is advanced to obtain the dynamic data of the network flow in emergencies under special events.

4.1 Algorithm flow

Commonly, the traffic demand of the road network varies. Under special events, background *OD* is considered to be fixed in the process of dissipation, and *OD* produced by special events is supposed to keep constant in a little time-slice to simplify the problem. Once an emergency occurs, the attributes of link changes and the delays of links can be obtained by the CTM in current simulation time-slices. The impedance of the network exported from the simulation is regarded as the new impedance of the network imported into the next simulation time-slice. According to the new impedance of the network, the *OD* in this time-slice is assigned by the static multi-path allocation method[9], and the turning proportion for each intersection can be computed. After these, the parameters of the CTM in the new simulation time-slices are changed, such as input flow, turning proportion for each intersection and traffic management measures, and a new round of simulation runs. When the simulation in this time-slice ends, a new state of network flow forms, which is the basis of next simulation time-slice. By adjusting the attributes of the links and implementing traffic assignments with the static multi-path allocation method in each time-slice, continuous *OD* is assigned to the network, which is called the semi-dynamic assignment method. For example, when an emergency is cleared up, the information is input to the simulation process, then the attributes of the related link ($t = t_4$) are changed, and the parameters of flow also change until the management measures end at t_5, which can be obtained by using the semi-dynamic assignment method between t_4 and t_5.

4.2 Partition of simulation time-slices for assignment

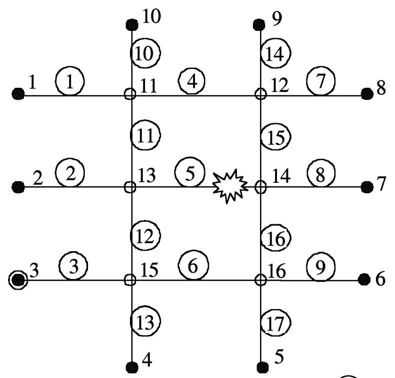
The partition of simulation time-slices for semi-dynamic assignment is determined by the variation rule of the traffic flow. Commonly, it is about 5 to 10 min[10]. Under special events, an emergency is required to be dealt with in good time, so it is often a short process to resume traffic. Consider the maneuverability of changing parameters. The time-slice is longer than a signal cycle. Here a time-slice of 3 to 5min is advised.

5 Example

5.1 Condition

Consider a simple network (see Fig. 2). 1 to 10 are traffic regions (Traffic region 3 is the location for special events), and 11 to 16 are intersections. Suppose that all the roads in the network are two-way, three-lane, 500-m-long roads. Background *OD* is fixed (see Tab. 1). The traffic demand produced by the special events is variable with the time (see Tab. 2), and its distribution in direction is considered changeless (see Tab. 3). All the intersections of the network are two-phased, and the initial controlling scheme is listed in Tab. 4.

Here we suppose that the emergency occurs at the site 100 m from intersection 14 on link 5 (connecting intersection 13 and intersection 14), and the flow from west to east is blocked at t_0 (t_0 = 10:20). Temporary traffic controlling measures are implemented at t_3 (t_3 = 10:25). The emergency is eliminated and the link is resumed at t_4 (t_4 = 10:35). At t_5



1 to 10 — Traffic region; 11 to 16 — Intersection; ① to ⑰ — Link

Fig. 2 The studied road network

(t_5 = 10:40), the initial traffic controlling scheme is implemented. Two signal controlling schemes for an emergency are listed in Tab. 5 and Tab. 6.

Tab. 1 Background *OD* matrix pcu/(5 min)

O	*D*								
	1	2	3*	4	5	6	7	8	9	10
1		100	50	250	200	200	250	250	200	150
2			50	200	150	250	300	300	300	250
4			50		50	150	200	200	100	200
5			50			50	150	150	200	100
6			100				100	100	250	200
7			100					100	300	250
8			100						100	250
9			100							50
10			100							

Notes: * The value in the third line is one-way demand from other traffic regions to traffic region 3, not variable with time. Others are two-way.

Tab. 2 Trip production under special events

Time segment (T = 5 min)	Traffic demand produced by special events/(pcu·(5 min)$^{-1}$)
1T	100
2T	150
3T	150
4T	150
5T	200
6T	300
7T	400
8T	400
9T	300
10T	300
11T	100
12T	100

Note: The value is one-way demand from traffic region 3 to other traffic regions, varying with the time.

Tab. 3 Directional sharing ratio of trip production under special events %

O	*D*								
	1	2	4	5	6	7	8	9	10
3	5	5	10	5	15	20	20	10	10

Tab. 4 Initial signal controlling scheme s

Intersection	North-south green time	Cycle time
11	70	120
12	60	100
13	70	120
14	60	100
15	70	120
16	60	100

Tab. 5 Signal controlling scheme 1

Intersection	North-south green time/s	Cycle time/s	Turning limit
11	70	120	
12	50	100	
13	70	120	Limiting flows from west to east, south to north, and north to south
14	50	100	
15	60	120	Limiting flows from west to east and south to north
16	50	100	

Tab. 6 Signal controlling scheme 2

Intersection	North-south green time/s	Cycle time/s	Turning limit
11	70	120	
12	60	100	
13	70	120	Limiting flows from west to east, south to north and north to south
14	50	100	
15	70	120	
16	60	100	

5.2 Simulation outcome

The simulation started at 10:10 and ended at 11:00. In the CTM, the simulation time segment is 5 s. Suppose that queuing vehicles in a certain link reach the upriver intersection, the intersection is regarded as getting into a jam. In fact, if the link gets into a jam, the upriver intersection does not always get into a complete jam due to the self-organizational characteristics of the vehicles. Here the most disadvantageous state is selected as the basis of simulation to study the maximal influence range of the jam. Tab. 7 gives the simulation outcome of the initial time of the jam in each intersection under the controlling scheme 1 (All of the following outcomes are solved under scheme 1).

Tab. 7 Initial time of the jam in intersection

Intersection number	Jam time in reality	Corresponding simulation time $t/(5\ \mathrm{s})$
11	10:23:20	160
12		
13	10:21:50	142
14	10:23:45	165
15	10:23:20	160
16		

At t_3(t_3 = 10:25) the traffic controlling scheme for emergency is implemented, and the jam of some links continue for a period of time. Fig. 3 shows the density ratio of different places in some links.

Link 3 is the only road connected with the location for special events and the whole road network. From Fig. 3(a) and Fig. 3(b), we can see that intersection 15 gets into a jam

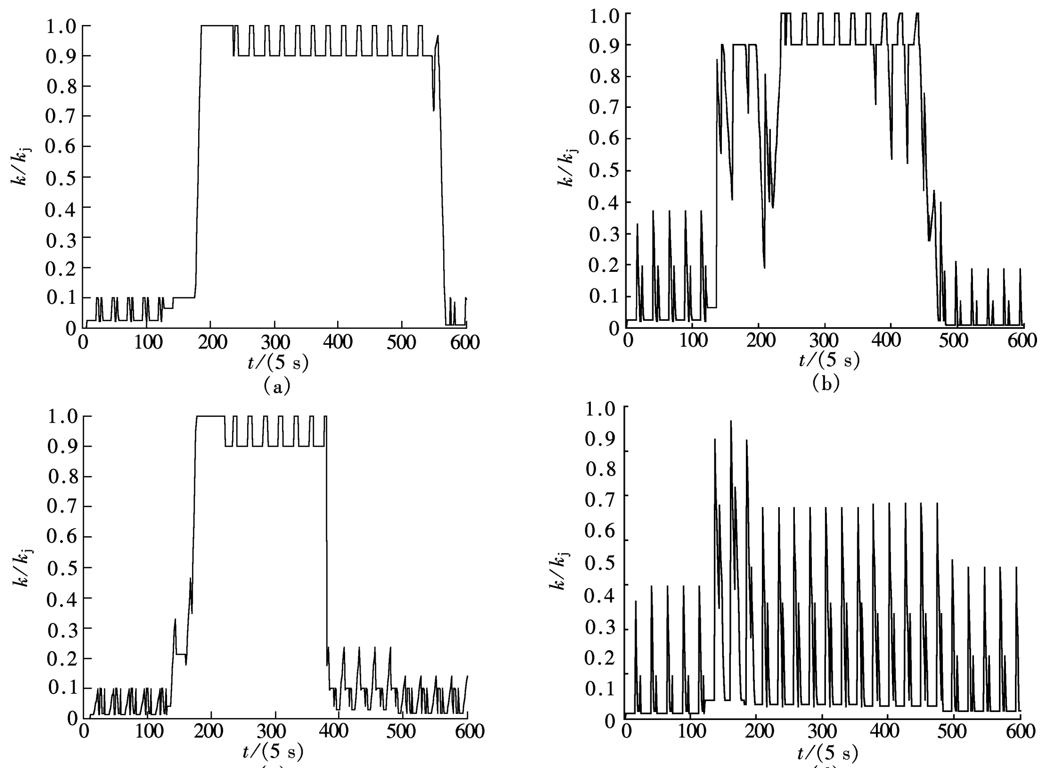


Fig. 3 Flow density ratio of some of the links. (a) The cell which is 50 m from intersection 15(link 3, west to east); (b) The cell which is 450 m from intersection 15 (link 3, west to east); (c) The cell which is 50 m from intersection 15 (link 6, east to west); (d) The cell which is 450 m from intersection 15(link 6, east to west)

at 10: 23: 20(t = 160 × 5 s, which affects link 3 heavily. Though traffic measures start at 10:25, the flow approaching intersection 15 remains saturated. At about 10: 52(t = 560 × 5 s), the saturation degree is decreased. The density of the place far away from the intersection in this link remains high for a long time until the number of vehicles produced by the special event reduces step by step(see Fig. 3 (b)).

Link 6 is affected by the jam of intersection 15. Because of the timely implementation of management, the site far away from intersection 15 does not get into a jam(see Fig. 3(c)) and only part of the link near intersection 15 gets into jam(see Fig. 3(d)). The jam does not reach intersection 16.

The traffic in those links connecting with the jam intersections varies in the same way as the traffic flow in link 6, as the traffic flow from west to east in link 2, the flow from north to south in link 10, and the flow from east to west in link 4, etc. The traffic in other links which are not connected with the jammed intersections is not saturated, such as link 7, link 9, link 14 and link 17, etc.

According to the simulation, the influence range of the emergency is shown as the area drawn by the dashed line in Fig. 4. Traffic of most links resumes at about 10: 40, and only link 3 resumes at 11:00.

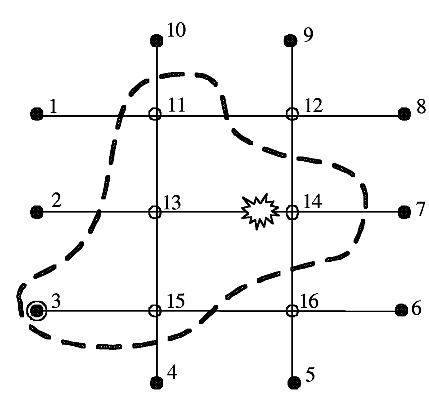


Fig. 4 Influence range of emergency in the road network

The traffic variety rule of the network is similar between the two traffic schemes besides there being little difference in the density of some links. The average delay of vehicles of the two schemes is 197 s/pcu and 232 s/pcu, respectively, which shows that the first scheme is better than the second one.

6 Conclusion

Based on the analysis of the influence of emergency, the idiographic expression in the CTM about traffic management measures under emergencies is studied in this paper. A semi-dynamic assignment algorithm is proposed under emergency, which is combined with the algorithm for logit multi-path traffic assignment and the CTM. By this method, the forming and dissipation of traffic jams under emergencies can be described in detail. According to the influence range of an emergency, the impact of the emergency can be known and the traffic management scheme can be evaluated.

Though the types of emergency are multiform and the mechanisms of jams are complicated, the proposed method is effective in actual traffic engineering. Personal path-choice action is affected by many factors, and the impact on traffic distribution by traffic controlling measures are the emphasis of this paper. The impact by measures of traffic guidance is not considered, which is a complicated direction of the research, and it is worthy of further sutdy.

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基于 CTM 的大型活动突发事件交通影响范围确定

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摘要:为了确定大型活动下突发事件的交通影响范围,以元胞传输模型(CTM)为基础,对大型活动中消散过程中交通流时空分布状况进行模拟研究. 结合突发事件下常用的交通管制和疏导措施的特点,将静态多路径交通分配方法与元胞传输模型结合,设计出适合突发事件下的准动态交通分配方法. 以一个小规模路网为研究对象,通过仿真研究了大型活动条件下路网交通流随交通控制方案的实时调整而变化的时空规律,提出了依据突发事件下各交叉口节点的拥堵时刻划定突发事件交通影响范围的方法. 通过对比车辆的平均延误指标,研究了不同交通管控方案下交通拥堵的疏散效率. 算例结果表明,基于 CTM 的准动态交通分配方法可以细致地描述路网中任一位置交通流的时空变化,确定突发事件的动态影响范围,可以为大型活动突发事件下交通组织方案的制定和评价提供定量依据.

关键词:交通管理;大型活动;突发事件;影响范围;元胞传输模型

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