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A traffic flow simulation model for net work signal control

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1. Introduction:

In the study field of traffic signal control, traffic simulation models are developed to evaluate the measurement of effectiveness (MOE) of the planned signal control system. In contrast with other traffic flow models, signal control aimed flow models pay particular attentions on simulating the traffic phenomena with respect to intersections. The geometric conditions of intersections, such as the number of lanes, the existence of exclusive right turning bay, etc. should be integrated with the flow phenomena, such as physical queuing in the model. there many kinds of traffic simulation models have been developed on various purposes. However, signal control aimed simulation models are unbelievably insufficient either in quantity or quality. Among such models, flow simulation module in TRANSYT-7F (Courage k., and C. Wallace, 1991), and SCOOT (Robertson, D. I., and R. D. Bretherton, 1991) are representatives, but still lack of consideration on many quite important issues, such as queue spill-back that often occurs between short spacing intersections. This paper addresses the methodology and practice of developing a traffic flow simulation model that aims at operating traffic signal control. In the model, some crucial issues which have significant effect on network signal control, but were neglected or avoided in common models, are illustrated theoretically and then simulated as well.

Key words: Traffic control, Simulation.
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2. Outline of the simulation model

It is particularly important in analyzing traffic in signalized networks that one does not try to describe anything more than is necessary to answer specific questions. The model to be introduced is not a comprehensive traffic flow simulation model, which tries to describe any kinds of traffic phenomena. Instead, it's based on a fully macroscopic traffic flow description. Each link is given a predetermined q-k relation, and thus, traffic state is characterized by the corresponding traffic density, traffic volume and mean speed. Also the route choice behavior is predetermined either by dynamic assignment or fixed route outside. No explicit behavior such as car following, overtaking, lane change has been described in the model. The methodology used to simulate vehicular movement of each vehicle (or vehicle group) is so called as "jump method" by the author. That is, like Fig.1 shows, the model does not simulate the physical movement of each vehicle along the link .

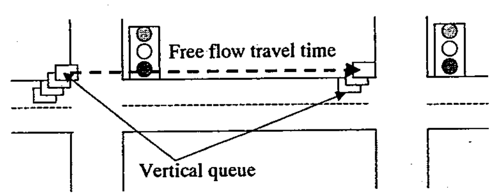

Figure 1. Methodology of simulating vehicle movement

Instead, based upon the principle of point queue, it focuses on simulating the behavior at two ends of the link, i.e. entrance and exit. We presume vehicles will travel at the free flow travel time and form vertical queues at each intersection. If all moving conditions are satisfied, the vehicle would move from one link to next link directly as if it "jumps off" the real distance of the link. Such moving conditions include: (1) free flow travel time of the link, (2) signal setting, (3) saturation flow rate of the lane group it departs from, (4) the availability of its next link. In this model, particular attention is paid to the realistic modeling of signalized junction phenomena. Especially, queue spill-back which often occurs because of high traffic demands exceeding capacity and/or because of closely spaced intersections, and turning bay blocking which often occurs due to high turning ratio are emphasized.

3. Turning bay blocking

Turning movement is a critical factor causing delay in urban networks. The most important characteristic is the manner in which turns are accommodated in the intersection. Turns may operate out of exclusive or shared lanes, with protected or permitted signal phasing, or with some combination of these complex conditions. In the case that the right turn ratio is high, sometimes turning bay will be fully occupied by right turn vehicles. If this happens, the capacity of the adjacent through-left shared lane will drop severely. Thus, if the signal can not serve all of the right turning vehicles in each cycle, the queue on this approach will grow rapidly and drives to heavy congestion soon even if total arrival rate is not sufficiently high. In order to present the blocking phenomenon due to the turning bay, a queue is made in front of the turning bay, and called as the 'blocking queue'.

The lane choosing is presumed to be performed at the entrance of each link and there is no lane changing behavior once it chooses a lane. Furthermore, we propose that each individual lane choosing behavior would sequentially balance the system during some period of time, and as the result, vehicles will be evenly distributed on the lanes. Fig.2 shows the locations of lane choosing and queues.

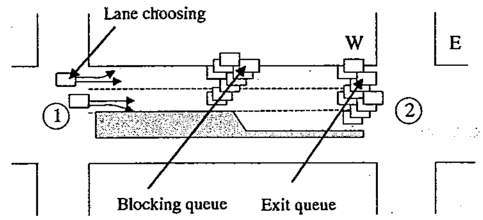

Figure 2 lane choosing, blocking queue and exit queue

After choosing the lane, a vehicle will firstly enter the 'blocking queue', if it is on the through-left shared lane, (e.g. the outer lane in Fig.2) it will be moved to exit queue directly, while if it's on the through-right shared lane (e.g. the mediate lane in Fig.2), whether it can move to exit queue currently is dependent on the condition of occupancy of the bay area, which includes not only the turning bay but also the relevant part of its adjacent lane. In this case, we have to check the turning information of the arriving vehicle and the number of vehicles in the corresponding bay area as well. If the area is fully occupied at the moment, the arriving vehicle has to wait in the blocking queue and will not be moved to exit queue until the bay area is available.

4. Shock wave

Traffic signals may become unexpected bottlenecks when queue spills back from a down stream signal impeding or blocking the output of an upstream signal. If downstream queue spills back, the leading vehicle on upstream link can not pass through the intersection even if signal setting and saturation flow conditions are satisfied currently. Sequentially the following vehicle has to stop and the queue forms at upstream intersection too. Therefore, the information of if and when a queue from downstream intersection will back up to the upstream intersection is extremely important. This problem is equivalent to that of determining if and when the shock wave will propagate to the upstream intersection. Fig.3 illustrates the relation between shock wave and the point and physical queues. In the theory of "kimematic waves," it gives a method to evaluate shock.

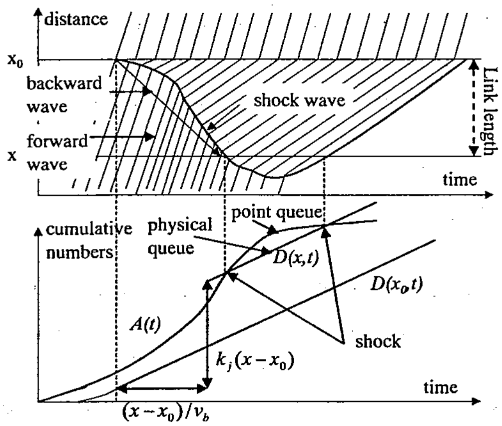

Figure 3 kinematic wave and the cumulative figure

In particular, if the flow-density relationship is presumed to be piecewise linear and has only two wave speeds as shown in Fig.4, Newell (1993) proposed the simplified kinematic wave theory. According to this theory, we can simplify the work of simulating shock wave by a large scale.

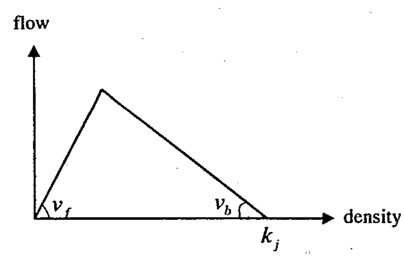

Figure 4 Flow-density relationship

If we look at Fig.3, we can find two kinds of waves: the forward and the backward waves. We can present the backward wave by moving the cumulative departure horizontally by a time displacement $\Delta x / v_b$ and vertically by an amount $k_j \Delta x$ (where, v_b is the velocity of backward wave, k_j is jam density and Δx is the link distance). If this moved cumulative departure curve intersects with the cumulative arrival curve, i.e. shock occurs, then we can obtain the real cumulative arrival by taking the lower part of the crossed curves. As a result, we can see from Fig.3 that, if we take physical queue into account, the cumulative departure of upstream $D(x,t)$ (arrival of downstream) is actually controlled by that of downstream $D(x_0,t)$. As described above, by using this method, the work of simulating shock wave becomes possible and does not take too much memory of computer.

5. Simulation results

(1) The result of turning bay blocking

The simulation result of the situation shown in Fig.2 is illustrated in Fig.5. The signal timing of intersection 2 is: cycle length, 100 second; loss time, 10 second; E-W direction green time 50 second, and 40 second for through and left turn movements and 10 second for right turn, right turn movements are all accommodated in the exclusive right turning bay with the storage of 5 vehicles. The arrival rate of vehicles is 1440 units per hour with 20% right turn. The scanning time is 0.5 second and simulation time is 1000 seconds (10 times of cycle length), thus, the arrival of through and left turn vehicles during the simulation time is 320 units and arrival of right turn is 80 units. The saturation flow rate of each approach is supposed to be ideally 1800 units per hour. In order to illustrate the effect of turning bay blocking, Fig.5 shows two results of cumulative departures. If we do not consider the blocking effect, the capacity of the exit approaches serving through and left turn vehicles is enough to serve the total arrival during each cycle, thus the departure is the upper curve. Otherwise, if we take the effect of turning bay blocking into account, the result is the lower one. The difference between the two curves is the number of vehicles sacrificed due to the blocking, i.e. the number of decrease in the capacity.

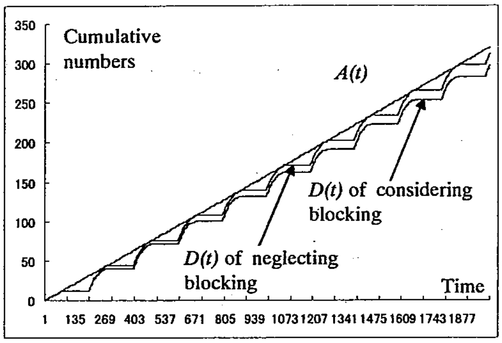

Figure 5 simulation of turning bay blocking

(2) The result of queue spill-back

As described in section 4, when we concern with physical queue in the simulation model, using the "simplified kinematic wave theory", we may deal with the spill-back problem by moving the cumulative curves. And if the moved departure curve is crossed with the arrival curve, we obtain the real arrival curve by taking the lower bound of the crossed curve. Fig.6 shows the simulation result of spill-back phenomenon.

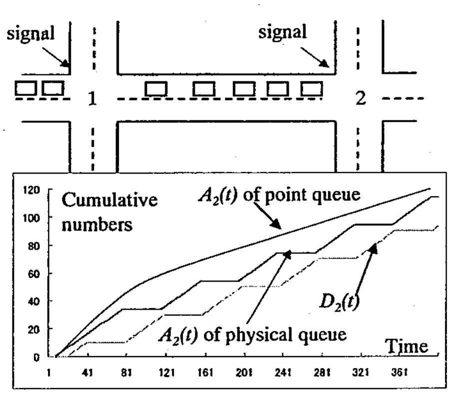

Figure 6 simulation of queue spill-back

The queue forms at downstream intersection 2 (signal setting is 40 seconds for both green and red interval), and propagates back over the upstream intersection 1. Under this situation, the cumulative arrival of intersection 2 (cumulative departure of intersection 1) $A_2(t)$ can be obtained by moving $D_2(t)$ horizontally and vertically some amount and if it intersects with the forward wave from intersection 1, the real arrive is the lower part of the crossed curve. From the Fig.6, we can see this clearly that, if we do not consider about effect of spill-back queue, the arrival is the upper curve, otherwise the $A_2(t)$ is controlled by $D_2(t)$, and the shape of the arrival curve is very similar to that of departure, as if it were 'tailored' by the cumulative departure curve $D_2(t)$.

6. Conclusions

This paper reveals the two main conclusions: (1) When making a signal control-oriented flow simulation model, by using the point queue methodology, one might concentrate his attention mostly on simulating the traffic behavior at intersection and neglect the explicit travel behavior on the link. (2) In the case that the physical queue should be taken into account, e.g. simulation of shock wave, under the simple assumption of linear q-k relation on the link, one does not need simulate the real path of the shock as introduced in "kinematic wave theory", which is too tedious and time consuming. Based on the simplified wave theory, one can achieve the tuff work by just moving and crossing the cumulative curves by some value, and the recipe is to choose the lower bound as the result.

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