STUDY OF PLATOON DISPERSION MODELS

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ABSTRACT

In this study, field investigation is made by means of videotapes which record traffic flows at several locations on two links in Changchun City, China. After processing the data, traffic flows at each location and vehicle speed distributions on different links are obtained for the platoon dispersion process. The platoon dispersion patterns from the observations are compared with those provided by the Transport and Road Research Laboratory (TRRL) in the United Kingdom. Different platoon dispersion models were used to fit the observed vehicle speeds and travel times, and their applicability was discussed. Simulations based on these models showed that the delay and length of queue at the downstream intersection are independent of platoon dispersion models and only depend on the flow and average travel time of vehicles from the upstream intersection.
1. INTRODUCTION

Vehicles departing from the stop-line of an upstream signal intersection generally form a motorcade. As vehicle speeds fluctuate during the motion, the motorcade will disperse before it arrives at the downstream intersection, which is called "platoon dispersion". Platoon dispersion is an essential phenomenon to be studied for building traffic models in traffic control system. Platoon dispersion models directly influence the optimization of signal timing schemes in arterial signal coordination because of their impact on traffic delay models. However, it is rather difficult and expensive to determine them compared with other traffic flow parameters such as traffic volume, saturation flow, speed and etc.

There are currently two kinds of probability-based mathematical models describing the dispersion of the platoon. One is the normal distribution model proposed by Pacey (1956) [1], and the other one is the geometric distribution model proposed by Robertson (1969) [2]. Both models suppose that the frequency of the occurrence of travel time along a certain road segment fits some corresponding probability distributions [3]. Nevertheless, Y.S. Quan (1989) found that the results using these two models in signal timing are almost the same [4]. H.G Retzko and M. Schenk (1993) analyzed the platoon dispersion model, which was developed by D.I Robertson in 1967. They found that the delay and number of stops were not very sensitive to the platoon dispersion factors [5]. This raises some curiosities about other platoon dispersion models besides the Robertson’s. How do different models affect the signal control optimization and which one has the least deviation when comparing with the actual figures? To answer these questions, authors planned a project to get data from field observation in Changchun City and went deep into the discussion.

2. FIELD OBSERVATION AND TRAFFIC FLOW DIAGRAM

2.1 Field Observations

With four video cameras, the platoon dispersion phenomena of the eastbound traffic on a link of Ziyou Avenue (two lanes in each direction) between Renming Avenue and Nanling Avenue were recorded during the morning-peak-hour, morning-flat-hour and morning-low-hour. Similar observations were made for the southbound traffic on a link of Nanling Avenue (one lane in each direction) between Ziyou Avenue and Panshi Avenue during the morning-peak-hour and morning-flat-hour. The video cameras were set up at locations A, B, C, D, and at I, II, III, IV, as shown in Figure 1. By multi-spot photographing, the arrival time and license plate number of each vehicle at each location were recorded. The data was used to calculate the vehicle’s travel time and average travel speed between observation locations, as well as the traffic flow at each location.
2.2 Traffic Flow Diagrams

In this study, traffic flow was calculated according to the vehicle counts in every ten seconds. The status of flows between 9:00am and 9:10am at the four observation locations on the Ziyou Avenue was shown in Figure 2. Figure 3 shows the status of flows provided by TRRL (Transport and Road Research Laboratory). Comparing Figures 2 with 3, the following indications are obtained:

1. The first observation location for Figure 3 was at the stop-line of the upstream intersection, while in Figure 2, it was at the exit of the upstream intersection. The data obtained from the latter is believed to be more precise for urban street intersections.

2. Figure 2 shows that the flow in several continuous cycles has a periodical feature. The platoons do not disperse significantly over 1350 m. This is consistent with the conclusion from J.M. Smelt, who claimed that the platoons were still substantially intact 1600 m downstream from the traffic signals [6].

3. PLATOON DISPERSION MODELS

The reason for the dispersion of platoon is the difference between vehicle speeds. Because one vehicle’s travel time on a fixed-length road section is inversely related to its speed, both speed and travel time can be used to study the platoon dispersion phenomenon.

With the observed field data, the distribution of vehicle speed was fitted with the Pacey model (normal distribution) and the lognormal distribution model. The distribution of travel time was fitted with Robertson model (geometric distribution), Poisson distribution model and negative binomial distribution model. Since distributions of speed and travel time are related to link length, traffic flow, and lane characteristics, different models were selected for different situations, as shown in table1, 2 and 3, based on the criteria of best fit. Some conclusions were reached during the model fitting:

1. Generally, with the increase of traffic flow from morning-low-hour to morning-flat-hour to morning-peak-hour, both the mean and variance of speed are decreasing. The variance of speed distribution on a two-lane link is less than that on a one-lane link when the link length is small, and they get closer as the link length increases;

2. Lane characteristics and traffic flows have little influence on the form of speed distribution;

3. Pacey model has broad applicability in modeling speed distributions;

4. Lognormal distribution is suitable for modeling speed distribution on long links;

5. Robertson model is suitable for modeling the distribution of travel time on short links;

6. Poisson distribution and negative binomial distribution are not appropriate to be applied to the modeling of the travel time distribution.

In the optimization of signal timing, the platoon dispersion model is used to predict
the profile of time-flow at the stop-line of the downstream intersection from that at
the stop-line of the upstream intersection, and then to calculate the platoon delay at
the downstream intersection. This raises a question: which platoon dispersion model
is most appropriate for using? Computer simulation of platoon dispersion and
queuing, which is discussed in the next section, could help us.

4. SIMULATION MODELS OF PLATOON DISPERSION AND QUEUING

In this study, GPSS (General Purpose Simulation System) was adopted for
simulation. The simulation model of platoon dispersion and queuing consists of three
sub-models: platoon formation model, platoon dispersion model, and queuing model.
In the platoon formation model, vehicle fleet forms in three modes. In the first mode,
the exit flow from the upstream intersection varies randomly instead of pulsantly.
The vehicles’ headway has negative exponential distribution. This mode occurs when
the exit flow from the upstream intersection is small or when the ratio of left-turn
vehicles is high. In the second mode, the exit flow from the upstream intersection has
the feature of pulse. This mode happens when the exit flow from the upstream
intersection is large. In the third mode, the exit flow from the upstream intersection
varies complicatedly, neither randomly nor pulsantly. The actual observed headway
data should be used in this case in the simulation.

The characteristics of the exit traffic flow from the upstream intersection determine
the platoon formation mode. The exit flow from an intersection is composed of
left-turn, right-turn and through flows from three approaches, which have different
arrival times determined by the signal timing. Therefore, intersections with different
signal timing schemes have different platoon formation modes. The intersections
with two typical signal timing schemes are discussed below.

For the most common two-phase signal intersection (shown in Figure 4), the flow
features at one exit (e.g., the eastern exit) were analyzed as following.

In phase I, left-turn vehicles from northern entrance and right-turn vehicles from
southern entrance drive out from eastern exit. In phase II, the through vehicles from
western entrance drive out from eastern exit. Usually the left-turn and right-turn
flows are much smaller than the through flow, so the traffic flow at the eastern exit
would be as low as nearly zero in phase I and as high as the saturation flow $S$ in
phase II. This type of traffic flow is obviously pulsant, as shown in Figure 4, so the
platoon forms in mode 2. In the morning-low-hour, however, the through flow in
phase II may be far smaller than the saturation flow $S$ and close to the turn flows in
phase I. In this case, the exit flow variation is random, which produces the platoon in
mode 1.

Four-phase signal timing is another common signal timing scheme, which is mainly
used for the situation when left-turn traffic flows are high. In this case, a protected
left-turn phase is provided for each approach, as shown in Figure 5. Let’s still use the
flow at the eastern exit for discussion. In phase I (or t1,) few vehicles drive out from
eastern exit, the flow at the eastern exit is nearly zero. In phase II (or t2), a large volume of through vehicles drives out from the eastern exit. After the yellow time interval (t3), left-turn vehicles from northern approach with a relatively large volume drive out from the eastern exit in phase III (or t4). In phase IV (or t5), only right-turn vehicles from the southern approach with a low volume drive out from the eastern exit. This kind of traffic flow is also pulsant, which forms the platoon in mode 2. The traffic flows observed at 9:00am at the eastern exit of the intersection on the Ziyou Avenue has the features described above.

For the platoon formation mode 1, the mean of headway is needed as input in the simulation, which can be obtained from traffic data observed on the Nanling Avenue at 9:00am. For mode 2, the platoon is created based on the characteristics of exit flow from the four-phase signal intersection. The parameters t1, t2, t3, t4, t5, q1, q2, and q3 can be estimated from the signal timing parameters of intersection 1(shown in Figure 1) and the traffic flow data observed on the Ziyou Avenue at 9:00 am. For mode 3, the platoon can be produced with the observed headways.

Six platoon dispersion models were adopted in the simulation:
1. Vehicle speed has normal distribution;
2. Vehicle speed has lognormal distribution;
3. Vehicle travel time has geometric distribution;
4. Vehicle travel time has uniform distribution;
5. Vehicle travel time has negative binomial distribution;
6. Vehicle travel time has Poisson distribution.

The vehicles' pulling-out-time-table at the upstream intersection can be produced with one of the three platoon formation modes. With the timetable and one of the six-platoon dispersion models that provides vehicles' speed or travel time distribution, vehicles' arrival time at the downstream intersection can be obtained. In this study, the queuing of vehicles was simulated for the one-queue-one-service-platform system using an event dispatch method. The purpose of this simulation is to find out the effect of different platoon dispersion models on vehicles' delay (including the full stop delay and the non-stop delay). Simulation results (averaged from ten runs of simulation) are shown in tables 4, 5 and 6. The parameters used in the simulation are as following: link length = 1000m, offset =0s, average speed = 11.3m/s, variance of speed = 2.5 (m²/s²), number of vehicles = 1000, upstream intersection cycle length = 80s; upstream intersection green time = 30s, saturation flow = 1 unit car/s (two lanes); mean headway of upstream platoon = 8s (mode 1), 3.2s (mode 2) and 3.3s (mode 3).

Some conclusions were drawn from the simulation results.

1. The queue lengths and delay values from different platoon dispersion models are close. This conclusion was obtained from all the link lengths used in the simulation (300m, 500m, 800m and 1000m).
2. With other parameters keeping constant, the queue lengths and delay values from different platoon formation modes are apparently different. The average delay decreases from mode 2 to mode 3 to mode 1.
3. The delay and length of queue at the downstream intersection are independent of
platoon dispersion models, and only depend on the flow and average travel time of vehicles exiting from the upstream intersection.

5. CONCLUSIONS

From this study, the following conclusions can be drawn:

1. Pacey model has broad applicability in modeling speed distributions;

2. Platoon dispersion process is closely related to the exit traffic flow characteristics from the upstream intersection, the link length and lane characteristics. However, the form of the platoon dispersion model does not have significant influence on the delay calculation.
ACKNOWLEDGMENT

This paper is supported by National Science Fund Commission of the People’s Republic of China (59978018) and the Outstanding Youth Fund of Jilin Province, P.R.China (20010114).
REFERENCE


2. G.M. Pacey, 《The Progress of a Bunch of Vehicles Released from a Traffic Signal》, *Road Research Laboratory Research Note No.RN/2665/GMP*, 1956.


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### Table 1. Selection of Distribution Models for Vehicle Speed / Travel Time between 1st and 2nd Locations

<table>
<thead>
<tr>
<th>Road Section</th>
<th>Time and link</th>
<th>Speed</th>
<th>Travel time</th>
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</thead>
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<tr>
<td>Lane No.</td>
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<td>Mean (km/hr)</td>
<td>Variance (km²/hr²)</td>
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</table>

Note: A - normal distribution; B - lognormal distribution; I – geometric distribution; II – Poisson distribution; III – binomial distribution; IV - negative binomial distribution.
Table 2. Selection of Distribution Models for Vehicle Speed / Travel Time between 1st and 3rd Locations

<table>
<thead>
<tr>
<th>Lane No.</th>
<th>Length (m)</th>
<th>Time</th>
<th>Link</th>
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Note: A - normal distribution; B - lognormal distribution; I – geometric distribution; II – Poisson distribution; III – binomial distribution; IV - negative binomial distribution.
Table 3. Selection of Distribution Models for Vehicle Speed / Travel Time between 1st and 4th Locations

<table>
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Note: A - normal distribution; B - lognormal distribution; I – geometric distribution; II – Poisson distribution; III – binomial distribution; IV - negative binomial distribution.
Table 4. Platoon Dispersion and Queue Simulation Results (Platoon Formed in Mode 1)

<table>
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<th>Dispersion model</th>
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<th>Max delay (s)</th>
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Table 5.  Platoon Dispersion and Queue Simulation Results (Platoon Formed in Mode 2)

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Table 6. Platoon Dispersion and Queue Simulation Results (Platoon Formed in Mode 3)

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