EFFECT OF DETECTOR LOCATION ON THE CONVERSION OF USER'S EQUILIBRIUM-BASED SPEED TO DETECTOR-BASED MEASURED SPEED FOR ARTERIAL ROAD APPLICATION *

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1. Introduction

With the ongoing application of Advanced Traveler Information System (ATIS) and Advanced Traffic Management System (ATMS), the accurate information of traffic situation providing to traveler, for example link or route speed and travel time, is becoming important. Previous researches on the estimation of speed and travel time mainly focused on freeway network rather than on arterial street. For arterial road, in general, the main objective in many researches is to estimate the average travel speed along the link or route given some traffic data and signal settings[1].

Speed is generally calculated based on the observed traffic data from traffic surveillance system. Among them, data from loop detector is a majority because of its widely used in real road network. Speed estimation from single loop is based on observed flow, occupancy, and a relationship between speed, flow, and density[2]. However, the effect of detector location on the measured speed is rarely examined since most of previous researches considered only for a specific case of detector location.

The traditional use of only volume-delay function (BPR function) has limited the accuracy of applying user equilibrium concept in traffic assignment and its related particularly during congested condition. A value of traffic flow can be interpreted as either at the light traffic or at the congested traffic. In contrast to traffic flow, speed and density are known to have a one-to-one relationship with the traffic condition. Therefore, it seems promising if traffic data obtained from detector can be fully utilized in this research area[3]. The consideration of speed and density in the model is expected in increasing of model accuracy at all level of traffic conditions.

Link flow as well as speed data can be used for the inverse estimation of route choice by minimizing the difference between model result and the observed value. However, speed obtained from model result cannot be compared directly to the measured speed from detector. Before the comparison between speed obtained from user equilibrium and speed measured from detector is carried out, the user equilibrium-based speed should be adjusted as to take the same effect as in the measured speed (i.e., the effect of detector location on the measured speed). With the ultimate goal of utilizing traffic data as much as available, the objective of this paper is to examine the effect of detector location on the measured speed at signalized arterial.

In the next section, the basic idea of model development is discussed. The idea is outlined in three simple questions as explained in section 3, 4, and 5. A numerical example based on the result of simulation model is shown in section 6. In the last section, the conclusion is drawn and future research is suggested.

2. Basic Idea for Model Development

In order to do a comparison between the speed obtained from user equilibrium concept and the measured speed from loop detector, there should be some adjustments to the user equilibrium-based speed. This is due to the fact that in arterial road, the measured speed would be different if loop detector is placed at different location on the same link. At signalized intersection, for example, speed measured near stop line may be less than speed measured at the mid-block of the same link because of more probability of observing stopped vehicles. At the upstream distance that is sufficiently far away from downstream intersection, one would expect none of signal delay effect occur at this point and therefore the speed at this point is influenced only from the interaction among vehicles. A similar idea in previous research is found in[4]. It considered only a portion of link and stated that signal delay associated with this portion is just a part of the total delay. Therefore, the first question is raised at here as to know how far from the downstream stop line that the measured speed at this point is no longer affected from intersection signal.

The second question can be addressed as how to define the speed at the boundary section. One might be able to know or calculate the speed at the first boundary point, the point where speed is no longer affected from signal, as considering only the influence of vehicles interaction. Another boundary point that the speed is possible to be defined in advance is at the point of stop line. At this point, the average speed may be said as the weighted average between the speed during stop, speed during the queue discharge, and speed when no effect of delay. The last question is defined as how speed varies from the first boundary to the boundary at stop line.

3. Defining the Distance of Signal Influence

This part addresses for the first question from previous section. The underlying principle of this part is from queuing analysis and basic traffic flow relationship. Consider a cumulative vehicles versus time diagram at a signalized intersection as

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shown in Figure 1, where the arrival rate (λ) and discharge rate (μ) are assumed constant. At the beginning of red interval, there is no overflow from previous cycle. Cycle length, effective red time, and effective green time are denoted as C, r, and g, respectively. The time duration of queue (t_Q), number of vehicles experiencing queue (N_Q), and maximum queue length (Q_M) can be calculated from:

$$t_Q = \frac{\mu r}{\mu - \lambda} \tag{1}$$

$$N_Q = \lambda t_Q \tag{2}$$

$$Q_M = \lambda r \tag{3}$$

The difference between number of vehicles experiencing queue and maximum queue length (i.e. $N_Q - Q_M$) is denoted as N'.

$$N' = \frac{\lambda^2 r}{\mu - \lambda} \tag{4}$$

From Figure 1, there would be N_Q vehicles which their associated speed are influenced from traffic signal. These vehicles would experience some delay time when arriving at the intersection. For instance, assume constant spacing between arrival vehicles (s_a) and also constant spacing between stopped vehicles (s_j). The spacing between arrival vehicles can be calculated from the ratio between arrival speed (v_a) and arrival flow rate (i.e., $s_a = v_a/\lambda$) whereas the spacing between stopped vehicles is calculated from the inverse of jam density (i.e., $s_j = 1/k_j$). If an aerial photograph is taken at an instant of time the red signal turns to green, the distance measured from the stopped line to the N_Q vehicle (i.e., L_M) can be defined as:

$$\begin{aligned} L_M &= L_1 + L_2 \\ &= Q_M \cdot s_j + N' \cdot s_a \\ &= \frac{\lambda r}{k_j} + \frac{\lambda r v_a}{\mu - \lambda} \end{aligned} \tag{5}$$

Figure 2 illustrates the spacing between the stopped vehicles and the spacing between arrival vehicles. This distance (L_M) can be regarded as the maximum distance that would be influenced from signal. However, the above equation is derived from the static point of view at the end of red interval. In fact, not a full length of L_M that vehicles begin to change their speed. The proposed equation for estimating the distance that signal influence to vehicles speed can be stated as the range of distance in between L_1 and L_M. A constant parameter, α, ranging between zero to one, is put into equation (5) in order to take the above effect into account.

$$l_0 = \frac{\lambda r}{k_j} + \alpha \frac{\lambda r v_a}{\mu - \lambda} \tag{6}$$

Arrival vehicles from the upstream intersection start subjected to delay from downstream intersection at the ending point of this l_0 distance.

4. Defining Speed at the Boundary Point

Up to here, there are two boundary points for an intersection approach. The first point is at the stop line and the second point is at a distance l_0 from stop line.

The average speed at the stop line, as explained in section 2, is considered as the weighted average between the speed during stop, speed during the queue dissipation, and speed when no queue. Figure 1 can be used again for the purpose of defining average speed at this point. Speed during stop is defined as zero and occurred only in the period of effective red, r. Speed during the queue dissipation is defined as speed when traffic flow at the capacity (v_m). This speed is occurred during the time period of ($t_Q - r$). The speed when no queue, is defined as the same as arrival speed, v_a, and occurred during the time period of ($C - t_Q$). The average speed at stop line, v_0, is then defined as:

$$\begin{aligned} v_0 &= \frac{0 \cdot r + v_m \cdot \frac{\lambda r}{\mu - \lambda} + v_a \cdot \left(g - \frac{\lambda r}{\mu - \lambda} \right)}{C} \\ &= v_a \cdot \left(\frac{g}{C} \right) - (v_a - v_m) \cdot \left(\frac{\lambda}{\mu - \lambda} \right) \cdot \left(\frac{r}{C} \right) \end{aligned} \tag{7}$$

The average speed at the second boundary point is rather simple and is directly defined as the arrival speed, v_a.

$$v_l = v_a \tag{8}$$

5. Defining Speed Curve

In this section the variation of average speed according to the associated distance from stop line is discussed. Intuitively, if a number of detectors are placed along the link under study with a small gap between each detector, the observed speed near the stop line would tend to decrease at a higher rate than at the distance far away from stop line. An example of the variation in speed as observed from different detector location is shown in Figure 3.

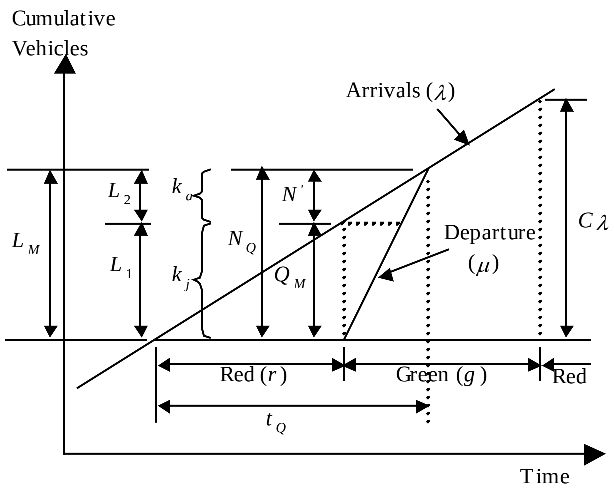

Figure 1. Cumulative Vehicles Versus Time Diagram at a Signalized Intersection

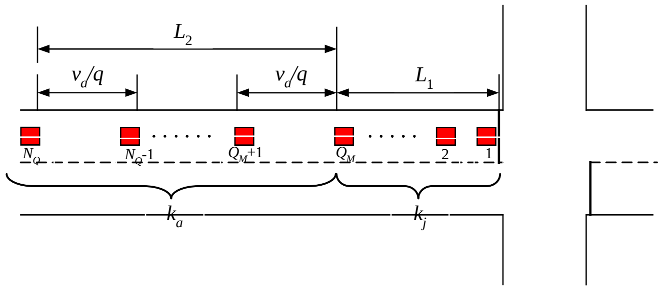

Figure 2. Spacing Diagram at the End of Red Interval

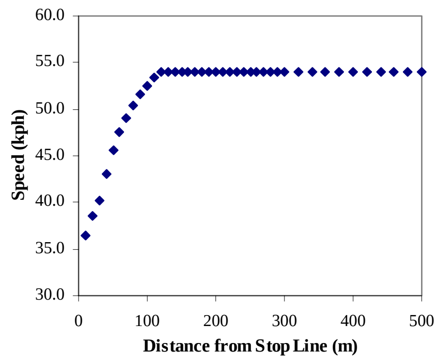

Figure 3. Variation of Average Speed as Observed from Different Detector Location

This example is taken from the simulation result of INTEGRATION software package assuming a virtual signalized intersection as will be explained in the next section. As can be seen, the average speed tends to be constant as long as the detector location is sufficiently far away from stop line. The average speed then tends to decrease rapidly as the vehicle approach the stop line. The starting point that the observed speed tends to decrease can be regarded as at a distance l_0 from stop line as explained previously. The variation of speed as a result of different detector location is assumed to have a parabola shape.

Speed at two boundary points is already known from the previous section. If the distance between a detector point and the stop line is denoted as L_d, the above two boundary conditions are written as:

Boundary 1: $L_d = 0, \quad v = v_0$ Boundary 2: $L_d = l_0, \quad v = v_a$

In case of parabola shape, only one-half of the curve is used. It can be seen that the vertex point of the curve is at boundary 2. The general form of speed variation when L_d ranging between zero and l_0 is as follow:

$$(L_d - l_0)^2 = 4a(v - v_a) \tag{9}$$

In the above equation, a is a focus of parabola. Substituting boundary 1 into equation (9), the focus of parabola can be obtained and thus equation (9) is rearranged as:

$$(L_d - l_0)^2 = \frac{l_0^2}{v_0 - v_a}(v - v_a) \tag{10.a}$$

thus

$$v = v_a - \left(\frac{L_d - l_0}{l_0}\right)^2 (v_a - v_0) \tag{10.b}$$

Equation (10.b) can be regarded as the proposed model for estimating speed if detector is placed at different location. The model can be used assuming that arrival speed, speed at capacity, arrival and discharge rate, jam density, and signal settings are known in advance. This equation can also be used for the purpose of converting the speed from user equilibrium as to be equivalent to the detector-based measured speed. For this purpose, the value of v_a in this paper is substituted by the value of link speed obtained from user equilibrium. This value is calculated by dividing link length with link travel time associated with the link volume at the equilibrium state.

6. Numerical Example

Due to the difficulty of obtaining average speed from a number of detectors located on the same link in real world, the numerical example in this paper is based solely upon the application of simulation package, INTEGRATION. A virtual four-leg signalized intersection is considered in this study with each approach has two lanes and a length of one kilometer. This long length is used in this study as to ensure that the link is sufficiently longer than the observed l_0.

The INTEGRATION requires the pre-specified value of a number of variables in order to run the model. The cycle length of signal is set to 70 and 90 seconds. The ratio of effective green time to cycle length of the link under observation is set to 0.5 and 0.7. Free flow speed is specified as 60 and 70 kph while the speed at capacity is set to 30 and 40 kph. A constant value of 120 vpkpl is set for jam density. The discharge rate is specified as equal the saturation flow rate and is set to 2200 and 2400 vphpl while a constant arrival rate of 525 vphpl is considered in this example. There are 32 cases in total, as a result of combining the above pre-specified values. A total number of 40 detectors are placed in the link under study at a spacing of 10 m between 10 and 300 m from stop line, and at a spacing of 20 m between 320 and 500 m from stop line. For instance, it is assumed that the arrival speed is already known for each case as a result from simulation run. Figure 4 and 5 shows the estimated speed versus the observed speed at all 40 detector locations by assuming the value of α in equation (6) as 0.5 and 0.5814, respectively. These values were obtained based on trial and error basis.

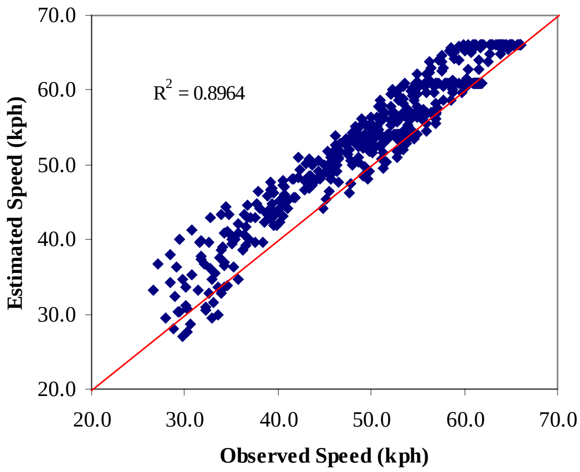

Figure 4. Estimated Speed Versus Observed Speed in Case of $\alpha = 0.5$

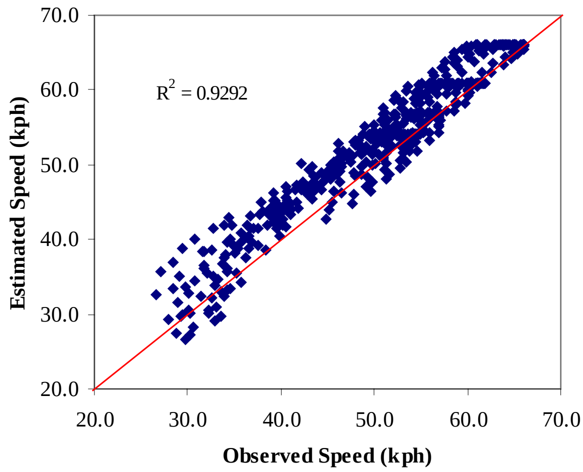

Figure 5. Estimated Speed Versus Observed Speed in Case of $\alpha = 0.5814$

Except for a bit overestimation, it can be seen that the proposed model can well explain the average speed as a result of different detector location.

7. Concluding Remarks

This paper examines the effect of detector location on the average measured speed at a signalized intersection. The final goal of the research is to fully utilize the observed data from loop detector in the application of dynamic traffic assignment based on the concept of stochastic user equilibrium. The proposed method is outlined in three steps: defining the length that vehicle start changing speed, defining the speed at boundary point, and defining the reducing pattern of speed within the boundary points. The underlying concept relies on the deterministic queuing process. An experiment of measuring a model capability on a virtual signalized intersection is conducted based on simulation program.

Despite the fact that the proposed model is intuitive, the topic in this area still can be improved. It is expected that the possibility of obtaining real world data would help in great improvement in this research area.

References

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