TURNING RATE ESTIMATION AT A SIGNALIZED INTERSECTION USING PROBE DATA

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1. INTRODUCTION

In Japan, ultrasonic wave detectors which are installed at the roadsides can measure the volume of passing vehicles over time. Since these detectors are located at 150, 300, 500, and/or 1000 m distances from the stop line (Traffic Bureau, National Police Agency, *et.al*), they cannot tell which direction the vehicles took after passing the intersection. This directional flow demand or turning rate is important in delay estimation which can be valuable information for evaluating the effectiveness and optimizing the timing of traffic signals.
The objective of this study is to formulate a methodology for estimating the turning rate of vehicles approaching an intersection by using detector data and probe data from infrared (IR) beacons. IR beacons can collect the ID number, time of passing, and information on present and previously passed beacons (Mashiyama, *et al.*, 2000) of cars with special on-board equipment.
These data are inputted to a traffic simulator to produce travel times under different turning rate cases. The trends in travel times are then analyzed in order to estimate the turning rates for each destination.

2. METHODOLOGY

2.1 Study Area

The study area consists of a four-legged intersection with upstream link O and downstream links L, R, and S. Link O has three major lanes: one lane for left-turning vehicles, two lanes for through traffic, and one right turn lane. In this study, the location of detectors and beacons for all links are assumed to be at the same distance from the intersection. The positions of the detectors are shown in Figure 1.

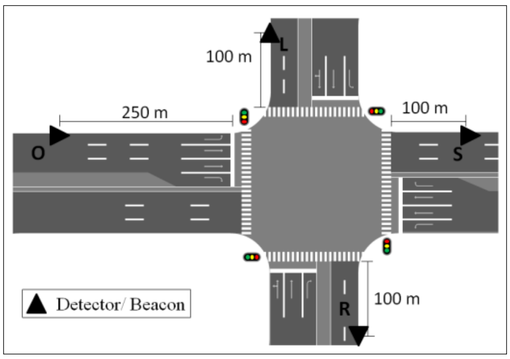

Figure 1. Layout of study area

2.2 Ground Truth Data

In place of actual field data, ground truth probe and detector data were generated using the Advanced & Visual Evaluator for road Networks in Urban areas (*AVENUE*) traffic simulator (Horiguchi, *et.al.*, 1996). 400 passenger cars were set to enter link O for 10 minutes. This traffic demand exceeds the link capacity by around 15%. The percentage of probe vehicles is assumed to be 10%, a value which is acceptable in some Japanese regions. This study only deals with heavy traffic conditions (i.e., demand is in excess of capacity) because light traffic conditions will not significantly affect the average travel times even if the turning rates are changed. Table 1 shows the ground truth turning rates used.
From ground truth data we know the following variables: a) GTR_p, the set of probe vehicle turning rates, b) GTR_{all}, the set of turning rates of all vehicles c) n, the total traffic demand and d) T_{di}, the passage time of the ith vehicle at the upstream detector (where i=1,2,…,n) . We assume that T_{di} has a resolution of one second. Note that GTR_{all} cannot be obtained from real-world data and must be estimated from GTR_p, n, and T_{di}.

Table 1. Ground Truth Turning Rates

Destination	Turning rates	
	All vehicles, GTR_{all}	Probe vehicles, GTR_p
Left	25%	30%
Right	20%	20%
Straight	55%	50%

2.3 Traffic Simulation

A series of simulation runs are conducted to estimate the ground truth turning rates, GTR_{all}. For each simulation run, a set of turning rates, ETR_{all} is assumed. Based on these, a destination is randomly assigned to each non-probe vehicle. The entry times and destinations of the probe vehicles are the same as those in the ground truth data. T_{di} is used to schedule the entry times of the n vehicles into link O. These data are inputted to the simulator and the travel time of the probe vehicles between the upstream and downstream detectors are obtained. For each assumed ETR_{all}, the procedure described above is repeated 100 times, each time changing the destinations of the non-probe vehicles.
We assume that the values of ETR_{all} are close to GTR_p. We then analyze 11 cases where the turning rates are within ±10% of the probe values. In this study, the turning rate of vehicles bound for link R is kept constant because varying it requires additional treatments and considerations such as the effect of oversaturation in the right turning lane on adjacent lanes. This issue will be

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addressed in future work.

3. TRENDS IN PROBE TRAVEL TIMES

Under light traffic conditions, slight increases in traffic demand do not affect the travel time of vehicles because on the average, they are travelling at free flow speed. This is not the case for oversaturated conditions where the travel times follow a linearly increasing trend due to queuing and intersection delay. This trend continues for some time even if the traffic demand is reduced. Consequently, a decreasing trend will be observed if the traffic demand is significantly reduced until all the queued vehicles have been accommodated. We quantify these trends by fitting a least-squares line to a scatter plot of the vehicle entry times versus the average probe vehicle travel times (Figures 2a and 2b). Because this method is based on trend lines, the estimation methodology proposed in this study requires that travel times follow a linearly increasing or decreasing trend which is continuous.

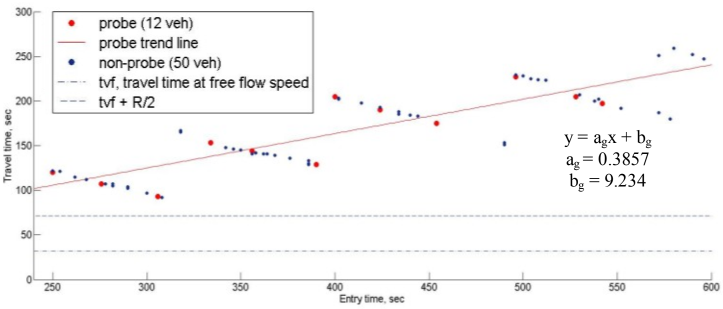

Fig 2a. Ground truth travel times for vehicles bound for link L

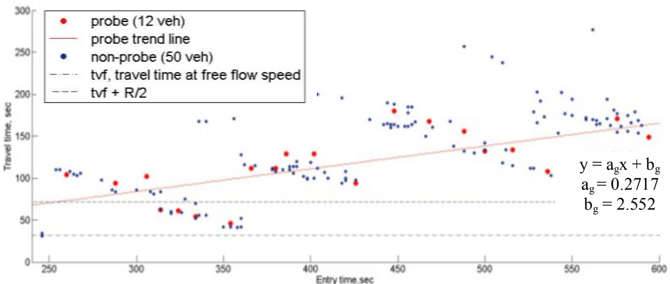

Fig 2b. Ground truth travel times for vehicles bound for link S

4. SENSITIVITY ANALYSIS

For each of the 11 cases the scatter plot of t_e , the entry time versus $\bar{t}_{i\text{-}n}$, the average travel time of probe vehicle i for the 100 simulation runs in Case n was constructed separately for probe vehicles bound for links L and S. The intercepts a and slopes b from the linear regression equation of each plot are normalized using the following equation (the same equation also applies for the slopes to obtain b'_i):

$$a'_i = \frac{a_i - \bar{a}}{\sigma_a} \qquad (1)$$

where, a_i : intercept of the scatter plot for Case i
$\bar{a}$: mean of a_i, where i=1:11
σ_a : standard deviation of a_i, where i=1:11
a'_i : normalized intercept for Case i

Equation 1 was also applied to calculate the normalized ground truth slope b'_g and intercept a'_g. The Euclidean distance ($distance_{iD}$) between the ordered pairs (b'_i, a'_i) and (b'_g, a'_g) are computed for probe vehicles bound for link D. The set of distances $distance_{iL}$ and $distance_{iS}$ are interpreted as measures of how close the trend of Case i is to the ground truth trend. This means that the lowest $distance_{iD}$ corresponds to turning rates that result to probe travel time trends having values that are closest to those of the ground truth. From the calculations, Case 9 (i.e. left turning rate = 25%) had the least $distance_{iL}$ while Case 8 (i.e. straight turning rate = 53%) had the least $distance_{iS}$. To reconcile these, the Euclidean distance $distance_{iLS}$ of the ordered pairs ($distance_{iL}$, $distance_{iS}$) from the origin are taken. The case with the least $distance_{iLS}$ corresponded to Case 9, with ETR_{all} values of 25% for link L and 55% for link S. These turning rates are equal to GT_{all}, the ground truth turning rates.

While the method was shown to estimate turning rates satisfactorily, the following must be considered when applying this method to real-world data: a. the difference in location between probe vehicles and detectors, b. the effect of parked vehicles, pedestrians, etc. as well as length of vehicles on overall traffic and c. cases where oversaturation does not occur in all directions.

5. CONCLUSIONS

This study was able to present a methodology for estimating turning rates at an intersection by using traffic volume information from detector and IR beacon data by considering the linearly increasing trend in average probe travel time under oversaturated conditions. The analysis shows that the trend line parameters (slope and y-intercept) of the entry time versus probe travel time plots are sensitive to changes in turning rates and can thus be used to estimate turning rates accurately. Once the turning rates are known, the average travel times and delay can also be estimated.

For future work, adjustments will be made to modify the simplifications made in this paper. The methodology will also be extended to consider undersaturated and nearly saturated traffic conditions.

REFERENCES

Horiguchi,R., Kuwahara, M., Katakura, M., Akahane., Ozaki, H., A Network Simulation Model for Impact Studies of Traffic Management 'AVENUE Ver.2', Proceedings of the 3rd ITS Congress, Orlando, Florida, October 1996

Mashiyama, Y., Kuwahara, W., Ikeda,R., Oda, T., Otokita,T., Estimation Of Traffic Patterns Analyzing Uplink Information. Proceedings of the 7th World Congress on Intelligent Systems,Turin , Italy, 6-9 November 2000

Traffic Bureau, National Police Agency, et. al., (no date) . ITS Developed by Japanese Police. *MODERATO* (pp. 87). Osaka, Institute of Urban Traffic Research