ANALYSING THE IMPACT OF DOWNSTREAM CONDITIONS ON SATURATION FLOW RATE

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1. Introduction

Saturation flow rate (hereinafter, referred to as SFR) is defined as, the equivalent hourly rate at which previously queued vehicles can traverse an intersection approach under prevailing conditions, assuming that the green signal is available at all times and no lost times are experienced[1]. It is important in transportation engineering because it serves as the basis for setting traffic signal timings, estimating the capacity of signalized intersections and evaluating mobility performance.

The SFR estimation procedure prescribed in the existing manuals[1),2)] include the adjustment of base SFR by different influencing factors, such as, lane width, approach gradient, heavy vehicle percentage, etc. However, among all these factors, the effect of downstream conditions is not considered. In urban areas where intersections are located relatively in closer distances and are mostly controlled by traffic signals in Japan, traffic flow could be easily affected by the downstream conditions, especially under high traffic volume when the downstream queue becomes longer. As the flow in such condition may become very small, it is necessary to consider the downstream conditions while estimating SFR.

This paper reports the preliminary results of the analysis on the influencing downstream parameters over SFR at an urban arterial, based on the field observation in Japan.

2. Hypothesis and Methodology

At any typical signalized intersection, vehicles would arrive during the red time and wait in the queue, as the signal display turns green, the vehicles will depart the intersection with a certain flow rate, which is generally regarded as SFR. However, if the queue in the downstream segment is still waiting for the traffic signal to turn green, the drivers of the upstream approach would be discouraged to accelerate to discharge. It is expected that the longer the downstream queue, the greater such an impact becomes (e.g. peak hour, or uncoordinated intersections). Thus, the SFR at the upstream is expected to be largely affected by the downstream conditions.

In order to investigate the relationship between the SFR and the downstream conditions, several parameters are considered, also shown in Fig. 1:

- Percentage of the available space behind the standing queue in the downstream segment ($P_{S,Q}$): It is expected that as $P_{S,Q}$ decreases the SFR decreases. It should be noted that, if the queue is moving, it is not considered under this definition.
- Number of moving vehicles behind the queue (N_{moving}): Behind the standing queue there would be some other vehicles which are still moving to join the standing queue. These vehicles will contribute in the increase of queue length and if these vehicles are moving slowly, the departure of the vehicles from the upstream intersection will be delayed, resulting in reduced SFR.

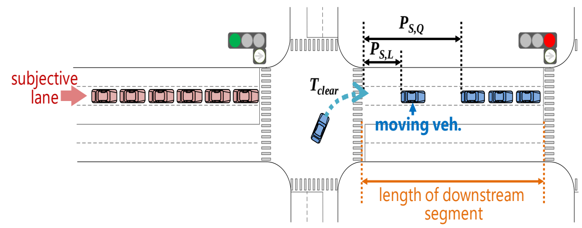

Fig. 1 Definition of analysis parameters

- Percentage of space available behind the last vehicle in the downstream segment ($P_{S,L}$): Among all the vehicles in the downstream segment, the standing vehicles in the queue or the moving vehicles, the last one would be the most influential.
- Time required from the onset of green until the last right turning vehicle from the crossing road clears the intersection completely (T_{clear}): At the onset of green at upstream intersection sometimes there are still some right turning vehicles which are entering the downstream segment from the crossing approach.
- Visibility and downstream signal display: If drivers departing from the upstream intersection observe that the downstream signal display is red, they may become demotivated and slowly discharge into the standing queue. The downstream signal display is determined by the offset between the upstream and downstream traffic lights.

Here, it is important to note that the parameters of $P_{S,Q}$, N_{moving}, $P_{S,L}$ as well as downstream signal display changes after the onset of upstream green time, thus the behavior of drivers from the upstream approach also changes dynamically. However, only the condition at the onset of green is considered in this paper.

3. Data collection and Processing

A video survey was conducted on Tuesday, September 13, 2016, along an urban arterial corridor (Yasukuni-dori) including a key intersection (Jimbocho) in Tokyo. Around 180 cycles were recorded on a rainy day, from 08:00~16:00 for the major through EB and WB approaches, which flow into Jimbocho intersection. Each approach consists of an exclusive right turning, two through and a shared through and left turning lanes. Lengths of the segments at the downstream of WB and EB approach are 196 and 167 m, respectively. In order to neglect the effect of turning vehicles the outer exclusive through lane is considered for the analysis in this paper. The traffic signal timing is actuated and the green time changes cycle by cycle. In this paper all the cycles in the analysis are the case that the signal display is green at the downstream, at the onset of green at upstream. The heavy vehicle effect is eliminated by removing their headways and the vehicle behind them from the queue. Thus, only 115 cycles with each cycle having more than 8 vehicles (only PCs) are analyzed in the following section.

The observed SFR is calculated for each cycle by using the following equations:

$$s_i = \frac{3{,}600}{h_i} \quad (1)$$

$$h_i = \frac{Tn_i - T4_i}{n_i - 4} \quad (2)$$

Where, s_i: SFR for cycle i [veh/h/ln], h_i: average saturation headway for cycle i [s], Tn_i: discharge time of n^{th} queued vehicle during cycle i [s], $T4_i$: discharge time of 4^{th} queued vehicle during cycle i [s], and n_i: number of queued vehicles observed during cycle i.

In order to know how much the observed SFR values differ from the SFR calculated by the current standards, the adjusted SFR value is calculated. It is calculated based upon the procedure recommended by the *Manual on Traffic signal control* in Japan[2] by considering the approach gradient and lane width adjustment factors.

4. Data Analysis and Discussion

The adjusted SFRs are calculated as 1,881 and 1,900 [veh/h/ln] for WB and EB, respectively. The difference is because of the different geometric conditions on both approaches, specifically the approach gradient (WB: -2.1%, EB: 0.8%). On the other hand, the average of the observed SFRs of all cycles are calculated as 1,485 and 1,460 [veh/h/ln] for WB and EB, respectively, by using the *average headway method*[3]. In this method, the average SFR is obtained by averaging of h_i from all the cycles and then dividing it into 3,600. The difference between the WB and EB is almost the same as that of adjusted SFR. Generally, one of the reasons for the difference between the adjusted SFR and the observed SFR could be due to the no consideration of the downstream conditions. Therefore, as the parameters for the downstream conditions, $P_{S,Q}$ and $P_{S,L}$ at the onset of green are analyzed in the following part.

Fig. 2 shows the effect of $P_{S,Q}$ at the onset of green over SFR. It indicates that the SFR reduces greatly with the decrease of $P_{S,Q}$ and showing increasing tendency as the $P_{S,Q}$ increases. The point circled in red indicates the worst condition when the SFR was affected the most by the downstream longer queue. For the queue with moving vehicles behind the queue, most of the points for the EB are at $P_{S,Q}$ = 100%, which is because of the traffic signal timing, at the onset of green most of the times there was no queue available at the downstream intersection, but the points ranges largely. In this figure, two different downstream conditions of queue with and without moving vehicles behind the queue are indicated by different symbols for both the approaches. Very few cycles had no moving vehicles behind the queue. The reason behind the largely ranging SFR could also be due to these moving vehicles behind the queue. Therefore, it is necessary to consider the influence of moving vehicles behind the queue in the downstream segment.

For that, Fig. 3 shows the effect of $P_{S,L}$ at the onset of green over SFR. It also shows the same two conditions of queue with and without moving vehicles behind it. In Fig. 3 most of the points for both WB and EB are at $P_{S,L}$ = 0% , which is because at the onset of green there were some vehicles around the entrance of the downstream segment. It was expected that higher the $P_{S,L}$ value is, the higher the SFR becomes, but Fig. 3 does not show any specific pattern and the SFR values are still

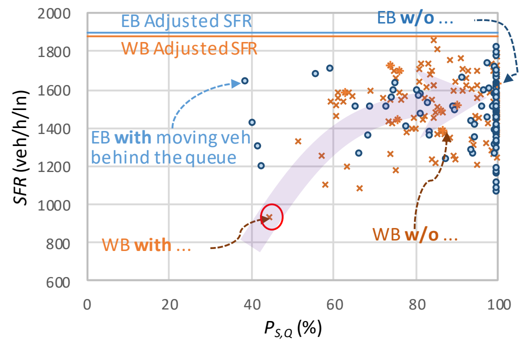

Fig. 2 Relationship between SFR and $P_{S,Q}$

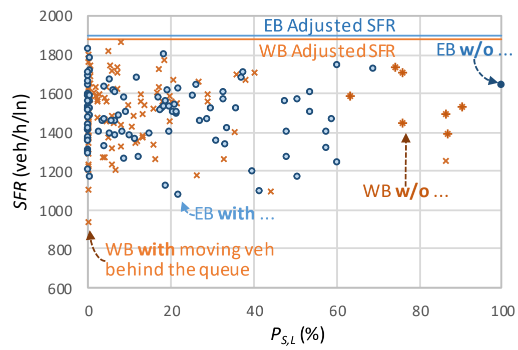

Fig. 3 Relationship between SFR and $P_{S,L}$

scattered over a longer range, which could be due to the dynamic change in the position of the last vehicle in the downstream segment and $P_{S,L}$ after the onset of green as each vehicle departs from the upstream intersection. In order to determine this kind of impact we need to investigate the downstream space availability for each departing vehicle from the upstream intersection.

The impact due to the number of moving vehicles behind the queue (N_{moving}) at the onset of green and the time required for the last right turning vehicle from the crossing road to clear the intersection at the onset of green (T_{clear}) are also analyzed, but their impacts are not as clear as of $P_{S,Q}$.

5. Conclusions and Future Work

Under higher traffic flow conditions, the queue lengths in the downstream segment becomes longer and reduces the SFR at the upstream intersection. Therefore, it is necessary to consider the downstream conditions while estimating the SFR. Among all the parameters analyzed, $P_{S,Q}$ has the most significant impact over SFR.

In the above analysis, the changing driver behavior due to the visibility and the downstream signal display has not been analyzed and also after the analysis this time, it is recognized that the length of the queue is changing dynamically as the vehicles discharge from the upstream intersection. Therefore, it is necessary to include these parameters also in the future work.

References

1) *Highway Capacity Manual*. Transportation Research Board, National Research Council, Washington, D.C., 2010.
2) *Manual on Traffic Signal Control Revised Edition*, Japan Society of Traffic Engineers, 2006.
3) James A. Bonneson, Brandon Nevers, Michael P. Pratt, and Gina Bonyani, *Influence of Area population, Number of Lanes and speed limit on Saturation Flow Rate*, Transportation Research Record Journal, No. 1988, 2006.