Lane Utilization Analysis of Shared Left-turn Lane Based on Saturation Flow Rate Modeling

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Abstract

Lane utilization analysis is an essential task in the planning and design stage of signalized intersections and arterials. This task becomes difficult to perform satisfactorily when shared permissive left-turn lane is present. It allows left-turners to proceed into the intersection together with conflicting pedestrians and usually results in unequal lane utilization by through traffic. To address this complex matter, a four-stage based saturation departure process from shared left-turn lane is proposed based on empirical analysis. Then it is incorporated into lane flow distribution procedure for lane utilization estimation. The case study shows that equal flow ratio principle by the proposed saturation flow rate modeling provides a better representation of traffic distribution than that of Highway Capacity Manual and equal lane volume strategy by Japan Society of Traffic Engineers manual. The consistent results of delay estimates assist in emphasizing the importance of saturation flow rate estimation also for performance evaluation.

1. Introduction

So far in the context of signal performance evaluation, the traffic system has always been assumed as one-lane approach or single service point. Within this simplified case the vehicles have no option than following the preceding vehicles and FIFO (First In First Out) rule holds in both arrival and discharging process. Generally, this macroscopic approach tends to provide a rather coarse way for signal

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performance analysis and sometimes seems unrealistic when interaction stands out between vehicles having different headway characteristics.

On the other hand, it is rather frequent in practice to observe more than one lane dedicated to a flow stream. A collection of lanes may serve one or more movements together. Lots of research (Akcelik 1989, Nevers 2002) also state lane-based analysis and performance measures are more desirable to support appropriate design decisions and accurate evaluation of signal timing plans (critical lane analysis). Hereinto, one special case deals with shared-used lanes, which exist in certain situations where space and other constraints make this measure expedient in the face of growing traffic demand. Due to different departure characteristics between turning movement and through flow, unequal lane utilization may appear and potentially affect the queue and delay at signals and vice versa.

Commonly in Japan, where vehicles travel on the left side of the road, the existence of shared left-turn lane serves as a disturbing factor contributing to imbalanced traffic distribution among through lanes. As shown in Fig.1 (a), an ideal case of shared left-turn lane utilization is equal to through lane, under the assumption that shared lane is preferred equally by through drivers. However during permitted phase, the attractiveness of shared-use lane to through traffic usually decreases when left turning vehicles have to filter through conflicting pedestrians, as illustrated by Fig.1 (b). Transient lane blockage and incurred delay would make following through vehicles hesitate to use shared lane for departure. On the other hand, under higher degree of saturation, through traffic does not have sufficient chances to use through lane only. A range of shared lane utilization by through traffic could arise under varying turning proportions.

![Through vehicles](image1)

(a) Ideal equal lane utilization

![Left-turn vehicles](image2)

(b) Unequal lane utilization by filtering traffic

Fig. 1. Lane utilization under the impact of shared left-turn traffic

Taken together, always representing shared lane with equal lane utilization as through lane fails to account for dynamic lane selection behavior as well as varying traffic performance at the individual lane level. It remains a prominent issue to accurately estimate shared lane utilization by through traffic, especially under higher flow conditions. Furthermore, the distribution of flows among lanes holds a key towards many other studies, such as queue formation or delay estimation, all being important to intersection and further arterial operational evaluation.

Therefore, the main objective of this paper is to investigate lane utilization by taking into account the effect of shared left-turn traffic. More specifically, the study is focused on exploring the influence on shared lane utilization by theoretically modeling discharging flow at shared left-turn lane, evaluating different lane selection strategies, and assessing the extent of such estimation errors on delay evaluation.

The paper is structured as follows. The first part reviews literature related to lane selection strategies, for most of which accurate estimation of shared left-turn saturation flow rate serves as a prerequisite. Next, the saturation departure process of shared left-turn lane is analytically modeled into four stages with distinctive characteristics. Then based on lane volume data collected in two signalized approaches, two
common lane selection strategies are evaluated as well as their indications for delay evaluation at signalized intersection. In the end, conclusions and recommendation for future work are provided.

2. Literature review

In real traffic, lanes can be differently preferred by vehicles for various reasons, e.g. staying on the lane to favor desired speed as well as waiting time at the signal. By far, a large body of methods or procedures can be found upon lane utilization estimation, which indicates several common estimation principles:

(1) Equal degree of saturation
The Swedish capacity guide (Bang 1978) and Australian method (Akcelik 1989) for lane flow allocation applies an equal degree of saturation to describe the results of lane choice behavior. Meanwhile, equal lane degrees of saturation mean equal utilization of available lane capacities.

(2) Equal flow ratio
The criterion of equal flow-to-saturation-flow ratio is being used in Highway Capacity Manual (2010). It differs from the previous one only because it does not consider the difference in effective green times among lanes.

(3) Equal lane volume
This principle is adopted by the current Japan Society of Traffic Engineers manual (2007). All the lanes within through lane group are assumed to bear equal traffic volume.

(4) Other methods
Besides, other criteria, e.g. equal average delay, minimum travel time or equal queue length, have been scrutinized by Bonneson (1998) and Nevers (2002).

Although a lot of work has been done upon lane utilization analysis, a systematic study on lane utilization is still worth conducting against field data, especially for through lanes sharing left-turn traffic in permitted phase. The conflicts between pedestrians and permitted left-turn flow definitely pose challenges to estimation of shared lane utilization. In this paper, as a small step, two common lane utilization estimation procedures, equal lane volume by JSTE (2007) and equal flow ratio by HCM (2010) are examined to assess which criterion is most reflective of actual lane utilization at signalized intersections. Note equal flow ratio is equivalent to equal degree of saturation given permitted phase in the Japanese case.

First, the prerequisite for this evaluation is accurate estimation of saturation flow rate for shared left-turn lane. According to the previous work by the authors (2011), a comparative analysis indicates both HCM and JSTE usually overestimate the saturation flow rates of shared left-turn lane in Japan. With this limitation, a direct use of their saturation flow rate functions can result in overestimation of through traffic distribution in shared lane, and further carry over errors for lane-based performance evaluation, as shown in Fig. 2(a).

3. Modeling of shared left-turn lane saturation flow rate

Therefore, based on empirical analysis, a four-stage based saturation departure process from shared left-turn lane is proposed, as illustrated by Fig. 2(b). Specific illustration for each stage is given in Fig. 3. In stage 0, vehicles continuously depart from shared lane until accumulated left-turn vehicles get blocked by opposing pedestrians at crosswalk and exceed the storage capacity within left-turn radius as well. The total blockage time, in stage 0, mainly depends on left-turn proportion and number of waiting pedestrians at the start of green time. After that, left-turn vehicles start up again and cross opposing flow by utilizing available gaps among randomly arrived pedestrians, represented by stage 0. Following note that as a
general case in Japan, pedestrian green phase usually ends 5 seconds earlier than the green phase (plus yellow time) for vehicles. This short green interval, namely stage P, would be crucial for saturation flow rate estimation in shared lane since both through and left-turn vehicles could fully utilize it with no pedestrian interruption.

![Fig. 2. Saturation flow of shared left-turn lane](image)

**(a) Overestimation of shared left-turn saturation flow rate**

**Fig. 2. Saturation flow of shared left-turn lane**

**(b) Shared departure characteristics**

Following presented are the detailed calculation methods of departure rates in each stage.

**(a) Stage M**

As mentioned above, the number of departures in stage M is closely related to two parameters: storage capacity of left-turn radius and left-turn proportion. Apparently, larger values of the first parameter would help lower the lane blockage probability and contribute to higher departure rates. According to Akcelik (1989), negative binomial distribution is usually introduced to approximate the potential departure rates for the cases with or without lane blockage. The departure from shared left-turn lane is taken as a series of Bernoulli trials. In applying it, discharging a through vehicle is defined as a successful event while for left-turn vehicle as a failure. The occurrence of lane blockage depends on whether the last arrived vehicle at the end of stage M is a left-turn vehicle or not.

In the case of lane blockage, the last arrived vehicle at the end of stage M is a left-turn vehicle exceeding the maximum storage capacity within left-turn radius, and then lane blockage occurs. The probability mass function of through departures can be modeled as
\[ f(x_i) = \left( x_i + (F+1) \right) (1 - P_L) \]

where, \( x_i \) is through departure rates (veh), \( P_L \) is the proportion of left-turn traffic in shared lane, and \( F \) is the storage capacity of left-turn vehicles within left-turn radius (veh).

The expected number of through departures in lane blockage case can be derived as

\[ E(X_i) = \sum_{x_i=1}^{M-1} x_i f(x_i) \]

where \( M \) is the maximum through departure in stage 1 and 2; \( M = S_T \times T_P \), where \( S_T \) is the ideal saturation flow rate of through lane (1900 vphg), and \( T_P \) is time duration of stage 1 and 2.

In the case of no lane blockage, the last arrived vehicle at the end of stage 1 is a through vehicle and altogether \( M \) through vehicles are expected to pass through the stop line with no interaction. Besides, left-turn departure rates would not exceed the storage capacity within left-turn radius. Its probability mass function can be estimated as

\[ f(x_2) = \left( M + (F + 1 - x_2) \right) \frac{(1 - P_L)^M}{F^{x_2}} \]

where, \( x_2 \) is left-turn departure rates (veh). Then the expected number of \( M \) through departures is:

\[ E(X_2) = M \sum_{x_2=1}^{M} f(x_2) \]

Therefore, the total expected number of through traffic departure in stage 1 would be

\[ D_T = E(X_1) + E(X_2) = P_L^{F+1} \sum_{i=1}^{M} \frac{(1 - P_L)(F + i)!}{F!(i - 1)!} + M(1 - P_L)^M \sum_{i=1}^{M} \frac{P_L^{F+1-i}(M + F - i)!}{(M - 1)!(F + 1 - i)!} \]

The expected number of left-turn departures in stage 1 is

\[ D_L = F \]

And the duration time of stage 1 associated with the mixed saturation flow can be computed as

\[ T_1 = \frac{D_T}{S_T} = \frac{D_T}{D_T + D_L} = \frac{D_L}{S_L} \times \frac{D_L}{D_T + D_L} \]

where, \( S_T \) is the ideal saturation flow rate of left-turn lane (1800 vphg/hour).

(b) Stage 2

Determination of duration time of stage 2 needs to consider pedestrian effects on blocked left-turn vehicles in Fig. 4, more specifically, pedestrian crossing time from both near and far side of the crosswalk. According to JSTE (2007), crossing time of pedestrians accumulated at the beginning of green phase from both near side and far side can be calculated as \( t_1 \) and \( t_2 \) in the following formulas. Here pedestrian platoon diffusion or two-way pedestrian flow interaction is not considered.

\[ t_i = \frac{L_1 + p_1}{V_p} \times \frac{p_i}{s_p \times W} \]

where, \( L_1 \) is the length of pedestrian influencing area, in which left-turn vehicles have to give way to pedestrians at the crosswalk; \( L_2 \) is the length of the rest part of crosswalk where pedestrians do not have any effect on left-turn vehicles; \( p_i \) and \( p_2 \) are near-side and far-side pedestrian volumes accumulated at the beginning of green phase; \( V_p \) is pedestrian crossing speed (m/s); \( s_p \) is pedestrian flow rate (ped/m/s); \( W \) is crosswalk width (m).
Since pedestrian crossing and left-turn departure proceed at the same time and pedestrians are supposed to have higher priority over vehicles at crosswalk, the duration time $T_p$ of stage $\mathbb{O}$ and $\mathbb{Q}$ would be dependent on the larger one of $t_1$ and $t_2$.

$$T_p = \max(t_1, t_2)$$  \hspace{1cm} (10)

Accordingly, the lane blockage time in stage $\mathbb{Q}$ can be obtained as

$$T_b = T_p - T_a$$  \hspace{1cm} (11)

(c) Stage $\mathbb{R}$

After dense pedestrians passing the crosswalk at the beginning of green phase, left-turning vehicles tend to wait for the available gaps in opposing pedestrian flows for departing. A gap acceptance departure state can be expected. Thereby, the left-turn departure rates in stage $\mathbb{O}$ is given by

$$S_{gap} = G_p \times \frac{e^{-\lambda t_c}}{1 - e^{-\lambda t_f}}$$  \hspace{1cm} (12)

Where $G_p$ is the total pedestrian demand (/h) in stage $\mathbb{O}$ ($\lambda = G_p/3600$); $t_c$ is critical gap of pedestrian stream (s); $t_f$ is follow-up time of left-turning vehicle.

In this study, the values of critical gap and follow-up time are determined as 5 and 2.86 seconds respectively, based upon the recommendation of Kawai et al (2007) and Alhajyaseen et al (2011). Considering through vehicles would depart at its saturation flow rates during this time period, the saturation flow rate in stage $\mathbb{R}$ is a combination of gap acceptance left-turn departure and saturated through departure, which can be interpreted by the following formula.

$$S_3 = S_{gap} \times P_L + S_T \times (1 - P_L)$$  \hspace{1cm} (13)

d) Stage $\mathbb{S}$

In this stage, pedestrians are not allowed to cross and only vehicles have additional green time, about 5 seconds to depart. The corresponding saturation flow rate at stage $\mathbb{S}$ can be simply calculated as a mixed saturation departure rate.

4. Estimation of Shared Left-turn Lane Utilization

Then, the built shared left-turn saturation flow rate model is incorporated into lane utilization estimation. Fig.5 depicts a flowchart of the procedure. The lane-by-lane analysis is carried out in a sequence of steps as explained below.

The first step in this analysis is preparing and inputting data. The required data refers to geometric, traffic and signal data for the subject intersection, as indicated in the saturation flow rate modeling. Then
an initial lane volume is set by equally distributing all the through and left-turn demand on choice lanes. After initial volumes are determined, an examination of the proportion of left-turning movements in the shared lane is necessary. If left-turn movement is exclusively assigned to the shared lane, a de-facto left-turn lane is created. Otherwise, go on to calculate the saturation flow rate of shared left-turn lane under the initial assigned left-turn proportion.

As the following step, different lane selection strategies would be implemented based on estimated saturation flow rates. If the criterion e.g. equal flow ratio cannot be satisfied, left-turn proportion in shared lane would be adjusted by re-assigning the initial lane volume distribution. This process is iterated until equal flow ratio is achieved for both through and shared lanes. At the same time, shared left-turn lane saturation flow rate can be determined. Finally, based on the lane volume and saturation flow rate estimation results, capacity, delay and level of service (LOS) are produced to support lane-by-lane performance evaluation.

\[ S_L = S_t \times P_L + S_T \times (1 - P_L) \]  

(14)

5. Field application

One signalized intersection example is used to test the proposed saturation flow rate model and lane flow distribution procedure. Field data was collected by video cameras from shared left-turn lanes on two approaches at Suemoridori-2 intersection in Nagoya, Japan, as shown in Fig. 6. This intersection is on a key route to downtown area, characterized by higher vehicle volume and medium to high pedestrian-bicycle demands during peak hours. And the intersection is fixed-time controlled with a cycle length of 140 seconds. Detailed site characteristics are given in Table 1.

Two lane selection strategies, equal flow ratio and equal lane volume, are evaluated against the field data to determine the preferred one for reflecting actual operation conditions. For the purpose of
comparison, the saturation flow rate estimates by the proposed 4-stage model and HCM (2010) are included in equal flow ratio calculation. According to HCM (2010), the saturation flow rate of a shared left-turn lane is to be determined as

\[ S = S_0 F f_{LT} f_{Lpb} \]  

where \( S \) is the saturation flow rate in vehicles per hour of effective green interval (vphg); \( S_0 \) is the ideal saturation flow rate, taken to be 1900 vphg per lane; \( F \) is the product of 6 adjustment factors related respectively to lane width, heavy vehicle, approach grade, parking, buses and area type; \( f_{LT} \) is the adjustment factor for left turns; \( f_{Lpb} \) is the adjustment factor for pedestrian-bicycle blockage.

![Fig. 6. Study site description](image)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>WB Approach</th>
<th>SB Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane configuration</td>
<td>LT,T,T,R</td>
<td>LT,T,R</td>
</tr>
<tr>
<td>Lane width (m)</td>
<td>3</td>
<td>2.75</td>
</tr>
<tr>
<td>Left-turn radius (m)</td>
<td>11.7</td>
<td>17.8</td>
</tr>
<tr>
<td>Left-turn angle (degree)</td>
<td>92</td>
<td>110</td>
</tr>
<tr>
<td>Storage capacity of left-turn radius (veh)</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>No. of receiving lanes</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Green time (s)</td>
<td>60</td>
<td>42</td>
</tr>
<tr>
<td>Cycle length (s)</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>Survey time</td>
<td>7:00-10:00</td>
<td></td>
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</tbody>
</table>

In the process of calculation, peak hour data are aggregated on a 5-minute basis, including lane volumes and opposing flows. Note that after screening out all the valid data, slightly different evaluation periods are chosen for two approaches. Fig. 7 and 8 give the estimation results of through traffic distribution in two shared lanes by different lane selection strategies. Their performance evaluation indices are illustrated in Table 2. Besides traditional mean and standard deviation, two other statistics, Mean Absolute Percentage Error (MAPE) and Root Mean Squared Error (RMSE), are introduced to evaluate the relative margin of estimation errors. MAPE returns the absolute percentage difference while RMSE returns the average absolute difference.
In Figs. 7 and 8, it is generally indicated by field observation that, due to the influence of conflicting pedestrian flows, shared lane utilization by through traffic usually bears a certain fluctuation. Owing to less through lanes available, SB approach corresponds to higher shared lane utilization as well as less fluctuation, as suggested by mean and standard deviation values in Table 2. On the other hand, for lane utilization estimates, the results given by proposed saturation flow rate modeling are more promising than the other two methods. RMSEs and MAPEs in Table 2 help demonstrate it. Possible reasons are explained as follows.

Table 2. Evaluation indices for shared lane utilization estimation

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<th>WB Approach</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>SB Approach</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Real</td>
<td>PROP</td>
<td>JSTE</td>
<td>HCM</td>
<td>Real</td>
<td>PROP</td>
<td>JSTE</td>
<td>HCM</td>
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<tr>
<td>Mean (%)</td>
<td>40.98</td>
<td>41.13</td>
<td>49.91</td>
<td>42.58</td>
<td>58.67</td>
<td>57.28</td>
<td>61.17</td>
<td>59.20</td>
</tr>
<tr>
<td>Std.dev (%)</td>
<td>12.13</td>
<td>12.58</td>
<td>10.78</td>
<td>12.99</td>
<td>7.10</td>
<td>8.53</td>
<td>6.61</td>
<td>7.90</td>
</tr>
<tr>
<td>RMSE (%)</td>
<td>-</td>
<td>4.46</td>
<td>9.90</td>
<td>4.53</td>
<td>-</td>
<td>3.26</td>
<td>3.31</td>
<td>2.45</td>
</tr>
<tr>
<td>MAPE (%)</td>
<td>-</td>
<td>8.70</td>
<td>26.18</td>
<td>10.59</td>
<td>-</td>
<td>4.86</td>
<td>4.76</td>
<td>3.10</td>
</tr>
</tbody>
</table>

As to equal lane volume strategy by JSTE, it ideally assumes each lane to be equally preferred and utilized, but it is often inappropriate to reflect real traffic situation. Commonly, the attractiveness, or technically capacities of approach lanes, would always differ due to different traffic compositions or movement interactions. Drivers cannot be expected to favor shared lane even when facing heavy
opposing pedestrian flows. In this sense, the equal lane volume strategy used in JSTE manual usually tends to overestimate through traffic distribution in shared lane.

For equal flow ratio estimation by HCM and proposed saturation flow rate modeling, a better performance is found in Table 2 by the proposed method although for most of the cases in Fig.7 and 8 only slight differences can be found between two curves. Considering the estimated saturation flow rates serve as the basis for lane utilization analysis, inaccurate estimation of shared left-turn saturation flow rates may result in traffic distribution deviations. To verify it, field observation of shared lane saturation flow rates are used for comparison with the estimates given by HCM and the proposed modeling, as shown in Table 3. The detail of field saturation flow rate measurement has been sophisticatedly introduced by the authors (2011).

It is found HCM usually tends to overestimate shared lane saturation flow rates while the proposed method gives the closest approximation, as shown in Table 3. Besides, it is worth mentioning that the saturation flow rate estimation by JSTE deviates most from real values. Interestingly, the trend of saturation flow rate overestimation is consistent with that of shared lane utilization estimation by through traffic. It indicates the accurate saturation flow rate estimation provides the prerequisite for lane utilization analysis.

<table>
<thead>
<tr>
<th>WB Approach</th>
<th>SB Approach</th>
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</thead>
<tbody>
<tr>
<td>Real</td>
<td>PROP</td>
</tr>
<tr>
<td>Mean (veh/h)</td>
<td>1349</td>
</tr>
<tr>
<td>Std.dev (veh/h)</td>
<td>138</td>
</tr>
<tr>
<td>RMSE (veh/h)</td>
<td>-</td>
</tr>
<tr>
<td>MAPE (%)</td>
<td>-</td>
</tr>
</tbody>
</table>

For the purpose of detailed saturation flow rate comparison, the authors carefully re-checked the original data by taking into account the influence of conflicting pedestrian flows. And it is found that the effects of conflicting pedestrians on shared traffic discharging are hard to quantify accurately, especially at the middle level of more random arriving pedestrian flows. For instance, in Fig.7, both estimates by HCM and the proposed method perform well from 7:35 to 7:50 a.m. covering 4 samples with lower opposing flow demands. Following from 7:55 to 8:20 a.m., owing to increasing pedestrian demands, disparity starts to state in two estimation curves with evident errors. Furthermore, during the rest time of evaluation period from 8:25 to 8:45 a.m., lane utilization rates experience a greater fluctuation due to more random arriving pedestrians. In this case the proposed method produces the relatively better saturation estimates over HCM. It is indicative that the empirical conflict-zone-occupancy approach in HCM (2010) may show drawbacks to accurately estimate the relevant occupancy regarding the stochastic influences.

The results above demonstrate the importance of shared saturation flow rate estimation cannot be overemphasized for lane utilization analysis. However in order to avoid saturation flow rate estimation error as much as possible, the key parameters in the proposed saturation flow rate modeling (e.g. pedestrian influencing area, critical gap) still need further investigation.

6. Implication for delay evaluation

Given the close relationship between traffic distribution and delay estimation, the authors go on to
explore its implications for delay evaluation. Inaccurate estimation of lane utilization would go on to
influence lane-by-lane delay estimation. So as to illustrate the influence, HCM delay formula is adopted
to quantify its effects. The average control delay per vehicle is computed by the following equation.

\[
d = d_1(PF) + d_2 + d_3
\]

Where \(d\) = control delay per vehicle (s/veh); \(d_1\) = uniform control delay assuming uniform arrivals (s/veh);
PF = uniform delay progression adjustment factor, which accounts for effects of signal progression;
\(d_2\) = incremental delay to account for effect of random arrivals and oversaturation queues; \(d_3\) = initial queue
delay, which accounts for delay to all vehicles in analysis period due to initial queue at start of analysis
period (s/veh).

In the following part, Figs. 9 and 10 concentrate on comparison of average delay estimation for
straight through lane and shared left-turn lane on two approaches by HCM, JSTE and the proposed
method. For the through lane on WB approach, satisfactory estimation results are achieved by the
proposed method as illustrated by the fit line in Fig. 9, while severe deviations are made by JSTE. As to
shared left-turn lane, the proposed method goes on outperforming its counterparts, although bearing
obvious fluctuations. The trends stay being consistent with lane utilization estimation in the previous
section. The similar results correspond to the case of SB approach.
By referring to the case of WB approach in Fig. 11, the reasons for the discrepancies between estimates would be explored.

It suggests equal flow ratio by the proposed method performs better than HCM as well as equal lane volume for through lane delay estimation, 58.57s v.s. 55.02s and 50.33s. As for delay estimation of shared lane, the proposed method produces the closest estimates of 63.15s compared to 62.47s for the real value. It is evident that, the disparity between delay estimates for through and shared lane stems from the estimation errors of lane utilization in previous section. Overestimation of through traffic distribution in shared lane definitely corresponds to higher delay in shared lane, meanwhile lower delay in through lane. And finally it would result in erroneous evaluation for operational performance. To further dig out the discrepancies, more light is shed on the basic principles of different lane utilization strategies.

Usually the lane capacities are not equal, as straight through lane and shared lane in this case. Unequal lane flows often occur in real instead of ideal equal lane volume. Apparently, equal lane volume fails to consider the difference between their discharging characteristics. Such a simple assumption in JSTE manual would usually lead to oversaturation conditions and delay overestimation in shared lane during high-demand periods, which in real are often alleviated by dynamic through shifting to median lanes.

On the other hand, equal flow ratio means equal utilization of available lane saturation flow rates or capacities (when effective green times are the same within lane group). In this case, equal flow ratio strategy by the proposed saturation flow rate modeling provides a relatively satisfactory estimation of shared traffic distribution and delay calculation. However, it is worth noticing that the fluctuations by equal flow ratio, as illustrated in Fig. 9 and 10, imply somewhat inaccurate saturation flow rate estimation at various levels of pedestrian demands. Serving as a basis for lane utilization and delay estimation, improvement of shared left-turn saturation flow rate model in light of the deficiencies calls for extensive field surveys in the future.

7. Conclusions

In signal operational evaluation, unequal lane utilization would potentially affect the delay estimation. Accordingly, this study analyzed the lane utilization of through traffic by taking into account the effect of shared left-turn traffic. Since the authors’ previous research have indicated that the current manuals tend to overestimate saturation flow rates for shared left-turn lane, a four-stage based saturation departure process from shared left-turn lane is proposed based on empirical analysis. Then it is incorporated into lane flow distribution procedure for lane utilization estimation. Two approaches at one typical signalized
intersection are used for case study.

It is found that filtered traffic state in shared lane cause through drivers to distribute themselves unevenly across straight-through lanes as well as in shared lane. But as the demand keeps increasing to near capacity, a more uniform use of all the lanes available for through traffic is indicated by real data. Besides, by comparing several lane selection strategies, equal flow ratio principle by the proposed saturation flow rate modeling provides a relatively better representation of traffic distribution than that of HCM and equal lane volume strategy by current JSTE manual. It indicates the importance of saturation flow rate estimation for shared traffic in lane selection estimation.

Given the close relationship between traffic distribution and delay estimation, the authors go on to analyze its effects on delay calculation. It is found equal flow ratio by the proposed method tends to take into account the operational difference between through lane and shared lane, and consistently provides satisfactory performance in delay estimates. The results are in accordance with Akcelik (1989). However, the findings should be validated through more data collection. Other lane selection strategies, e.g. equal perceived delay or travel time, equal queue length, also need to be investigated against field data. Additionally, since any approach is a steady-state approximation to a dynamic process (Akcelik 1989), microscopic analysis, such as driver’s behavior, traffic composition, are supposed to be noted within lane utilization evaluation.

Meanwhile, it is worth noticing that the fluctuations of lane utilization and delay estimates by equal flow ratio, imply somewhat inaccuracy existing in the proposed shared saturation flow rate modeling at various levels of pedestrian demands. In order to avoid saturation flow rate estimation error as much as possible, improvement of shared left-turn saturation flow rate model (e.g. pedestrian influencing area, critical gap) calls for extensive field surveys. The author would like to leave it as a future work.

References


